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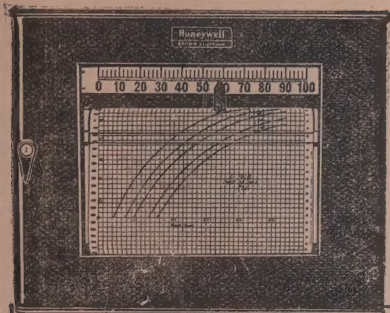
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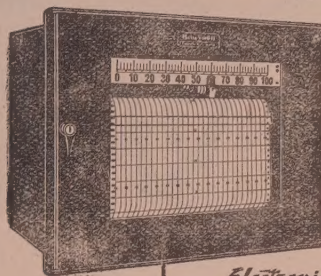
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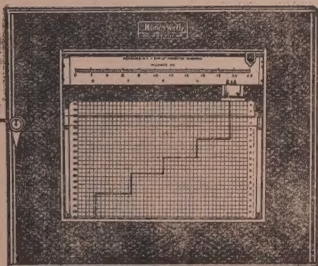
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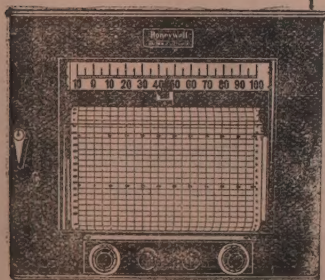
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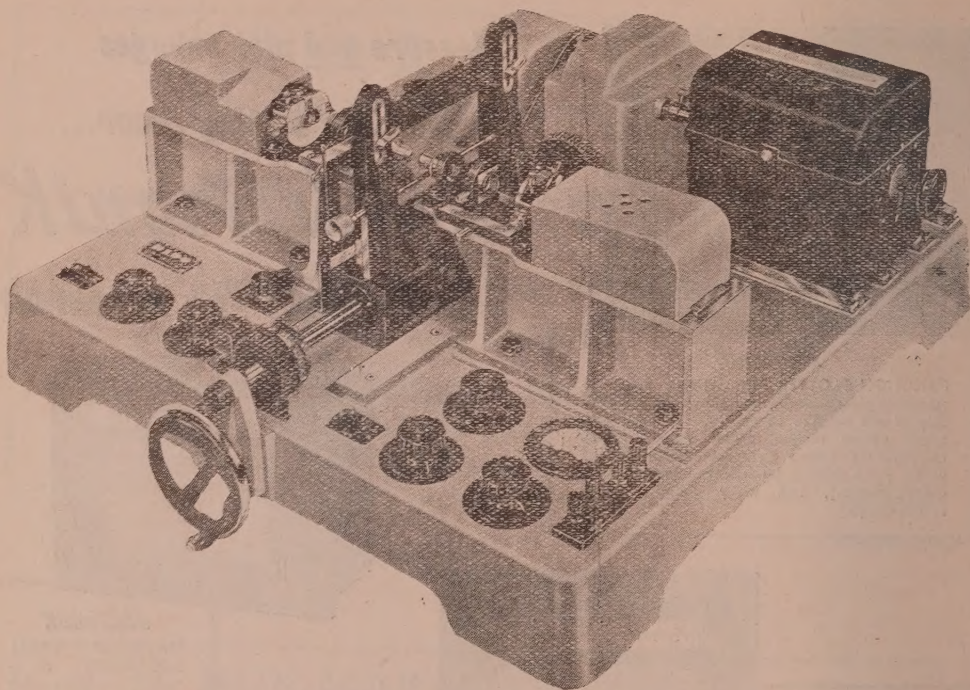
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INFLUENCE OF GEOMAGNETIC FIELD ON EXTENSIVE AIR SHOWERS OF COSMIC RADIATION

A. BHASKARA RAO AND P. S. GILL

DEPARTMENT OF PHYSICS, MUSLIM UNIVERSITY, ALIGARH

(Received, February 10, 1960)

ABSTRACT. G. Cocconi (1954) pointed out that the deflection of air shower particles in the earth's magnetic field should produce some ellipticity of shower structure, and hence the lateral distribution of electrons around the shower axis should not be circular, but elliptical, with the major axis in the East-West direction. This effect was investigated at Gulmarg (alt. 2710 m: 24°-36' N-geomagnetic lat.;) with two G.M. counter telescopes, for three separations 10 m, 25 m, and 40 m. The results show that there is a significant difference between the shower rates from East-West and North-South directions. This asymmetry in the shower rates is found to increase with the separation, and the zenith angle of the telescopes.

INTRODUCTION

G. Cocconi (1954) pointed out that D_m , the displacement of air shower particles due to the earth's magnetic field is not negligible in comparison with D_s , the projected lateral displacement due to multiple coulomb scattering, and this effect might be large enough to be detected as an asymmetry in the lateral distribution of electrons in air showers. It means the electrons are distributed elliptically, around the shower axis.

It has been evaluated in the first approximation, that the ratio of the two displacements is given by

$$D_m/D_s = 0.22 \cos \lambda / P.$$

Where

λ is geomagnetic latitude, and

P is air pressure in atmospheres.

The combined displacement is $D_{m+s} = [D_m^2 + D_s^2]^{1/2}$; so that

$$\begin{aligned} D_{m+s} &= D_s \left[1 + \left(\frac{0.22 \cos \lambda}{P} \right)^2 \right]^{1/2} \\ &\simeq D_s \left[1 + \frac{0.024 \cos^2 \lambda}{P^2} \right] \end{aligned}$$

P. Chaloupka (July, 1954) measured this effect on the top of "Lommicky Stit" (alt. 2634 m : 48° N. geomagnetic latitude) with two G. M. counter teles-

copies. The separation of the telescopes was 7 m. The telescopes were inclined at 45° zenith angle and successively directed towards East, West, South, and North. Fourfold coincidences were taken. He reported nearly 20% more showers arriving from the E-W direction than from N-S direction. Due to large statistical errors he did not draw any conclusion. Later Dubinsky, Chaloupka, *et al.* (1956) continued the investigation (alt. 1778 m: 48° N. geomagnetic lat.) in which they fixed up the position of the shower core, and measured the particle densities to the West and South of the core, at three distances 15.5 m, 30 m, and 50 m. Though they did not find any variation for 15.5 m, they observed 40% and 60% greater densities in the West direction than in the South for 30 m, and 50 m distances respectively. Even in this case the statistical errors were large. The present investigation was carried out at Gulmarg (alt. 2710 m : 24° - $36'$ N. geomagnetic lat.) with improved statistics.

EXPERIMENTAL

The experimental arrangement was similar to that of Chaloupka, and the block diagram is shown in Fig. 1. It consisted of two G. M. counter telescopes T_1 , T_2 , with two trays in each. In each tray there were four counters (size 52×584 mm) filled with Argon and petroleum-ether. The separation of the counter trays in the telescopes was 950 mm. The pulses from the trays were carried to the cathode-follower and from there to the coincidence circuit, through a low impedance coaxial cable, type KD-49. Only fourfold coincidences were recorded by the recording unit. The counter trays were mounted on an aluminium frame, which was fixed to a wooden stand in such a way that the telescope can be fixed at any particular zenith angle.

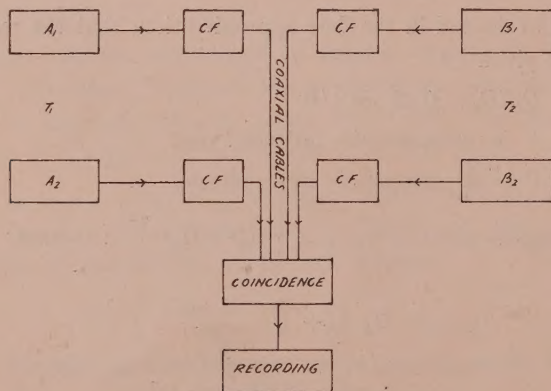


Fig. 1.

The asymmetry in the rate of showers was measured for three distances 10 m, 25 m, and 40 m between the telescopes. The telescopes were directed towards East, West, South, and North at zenith angles 0° , 15° , 30° , 45° , and 60°

and fourfold coincidences were recorded. Counters with a minimum plateau of 200 V were used in the experiment, and they were tested every day before starting the apparatus.

RESULTS AND DISCUSSION

The results of the experiment are given in Tables I, II, and III, for the three separations 10 m, 25 m, and 40 m. In any direction if the total number of counts recorded is M , during the total time T hours, then the shower rate in that direction is M/T per hour. The error in the shower rate is taken as $M^{1/2}/T$.

The first table represents the shower rates from East, West, South, and North directions with the corresponding errors. In Table II the average shower rate from East-West directions is taken as x and the average shower rate from North-South directions as y . Next, the ratio x/y is calculated for the three separations and all the zenith angles as shown. If the circular symmetry of electrons around the shower axis is to be correct, the ratio x/y should be unity. But it can be seen that in all the cases, without exception, the ratio is larger than unity and far beyond the statistical errors. This clearly indicates that electrons in extensive air

TABLE I

Counting rates of showers from East, West, South, and North directions with corresponding errors

	Zenith angle Z	Showers per hour from the East $N_e \pm \Sigma_e$	Showers per hour from the West $N_w \pm \Sigma_w$	Showers per hour from the South $N_s \pm \Sigma_s$	Showers per hour from the North $N_n \pm \Sigma_n$
10 m	0°	94.4 ± 2.5	—	87.0 ± 2.3	—
	15°	79.4 ± 1.9	81.5 ± 1.9	72.1 ± 1.7	72.1 ± 1.7
	30°	69.5 ± 1.5	75.0 ± 1.9	63.0 ± 1.5	61.2 ± 1.5
	45°	60.4 ± 1.5	66.1 ± 1.7	52.9 ± 1.3	53.8 ± 1.3
	60°	50.9 ± 1.3	58.0 ± 1.5	45.6 ± 1.2	47.4 ± 1.2
25 m	0°	58.9 ± 1.9	—	52.5 ± 1.6	—
	15°	49.5 ± 1.5	54.9 ± 1.7	40.0 ± 1.3	40.6 ± 1.2
	30°	45.0 ± 1.0	48.2 ± 1.5	33.2 ± 1.0	33.3 ± 1.0
	45°	40.2 ± 1.2	45.2 ± 1.5	28.2 ± 0.9	28.7 ± 0.9
	60°	35.0 ± 1.0	37.1 ± 1.2	22.4 ± 0.7	23.3 ± 0.7
40 m	0°	38.4 ± 1.5	—	30.0 ± 1.2	—
	15°	32.6 ± 1.2	35.3 ± 1.3	24.7 ± 1.0	24.9 ± 1.0
	30°	29.7 ± 1.2	32.6 ± 1.3	20.6 ± 0.9	20.2 ± 0.7
	45°	26.5 ± 1.0	29.5 ± 1.2	16.5 ± 0.6	16.5 ± 0.6
	60°	24.5 ± 0.9	25.9 ± 1.0	13.3 ± 0.6	13.3 ± 0.6

TABLE II

Ellipticity and percentage asymmetry of extensive air showers

	Zenith angle Z	Average shower rate from E-W $x \pm \Sigma_x$	Average shower rate from N-S $y \pm \Sigma_y$	Ellipticity $\frac{x \pm \Sigma_x}{y \pm \Sigma_y}$	Percentage asymmetry $F = \frac{2(x-y)}{(x+y)} \times 100\%$
10 m	0°	94.4 ± 1.8	87.0 ± 1.6	1.09 ± .029	8.2 ± 2.6
	15°	80.5 ± 1.4	72.1 ± 1.2	1.12 ± .027	11.0 ± 2.4
	30°	72.3 ± 1.2	62.1 ± 1.1	1.16 ± .028	15.2 ± 2.4
	45°	63.3 ± 1.1	53.4 ± 0.9	1.19 ± .029	17.0 ± 2.4
	60°	54.5 ± 1.0	46.5 ± 0.9	1.17 ± .031	15.8 ± 2.7
25 m	0°	58.9 ± 1.4	52.5 ± 1.1	1.12 ± .036	11.5 ± 3.2
	15°	52.2 ± 1.1	40.3 ± 0.9	1.30 ± .040	25.7 ± 3.0
	30°	46.6 ± 0.9	33.3 ± 0.7	1.40 ± .040	33.3 ± 2.8
	45°	42.7 ± 1.0	28.5 ± 0.7	1.50 ± .051	39.9 ± 3.3
	60°	36.1 ± 0.8	22.9 ± 0.5	1.58 ± .049	44.7 ± 3.0
40 m	0°	38.4 ± 1.1	30.0 ± 0.9	1.28 ± .053	24.6 ± 4.1
	15°	34.0 ± 0.9	24.8 ± 0.7	1.37 ± .053	31.3 ± 3.8
	30°	31.2 ± 0.9	20.4 ± 0.6	1.53 ± .063	41.9 ± 3.9
	45°	28.0 ± 0.8	16.5 ± 0.4	1.70 ± .064	51.7 ± 3.5
	60°	25.2 ± 0.7	13.3 ± 0.4	1.89 ± .078	61.8 ± 3.7

TABLE III

East-West percentage asymmetry of extensive air showers

Zenith angle Z	East-West asymmetry of extensive air showers		
	10 m:	25 m:	40 m:
0°	—	—	—
15°	2.61 ± 3.34	10.34 ± 4.32	7.95 ± 5.38
30°	7.61 ± 3.32	6.86 ± 3.82	9.30 ± 5.70
45°	9.01 ± 3.57	11.70 ± 4.45	10.71 ± 5.53
60°	13.03 ± 5.87	5.82 ± 4.31	5.55 ± 5.32

showers are distributed elliptically around the shower axis. The percentage asymmetry between the shower rates from E-W and N-S directions is given in the last column of Table II.

The errors in the ellipticity and the percentage asymmetries are calculated as follows :-

If (F) is a function of both x and y then the error in F is given by

$$\Sigma^2 = \left[\frac{d(F)}{dx} \right]^2 \Sigma_x^2 + \left[\frac{d(F)}{dy} \right]^2 \Sigma_y^2$$

where Σ_x and Σ_y are errors in (x) and (y), and Σ is the error in the function (F).

Then a graph is drawn with the zenith angles along the abscissa and the percentage asymmetries along the ordinate for the three separations of the telescopes. From the graph it is clear that there is a systematic increase in the asymmetry with zenith angle. It can also be seen that at any particular zenith angle the asymmetry increases with the separations of the telescopes. Of course the same arguments hold good for ellipticity also. The percentage asymmetry and ellipticity will increase by about 4 or 5% if the counting rates of showers only from West and South are taken into consideration, because the average shower rate from *E-W* is less than the individual shower rate from West, though the shower rates from North or South are exactly the same.

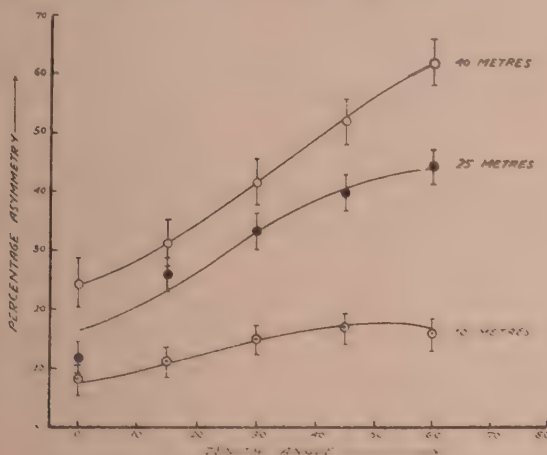


Fig. 2. Zenith angle versus percentage asymmetry.

Though the main aim of the investigation is to find out the geomagnetic effect on extensive air showers, there is one more interesting point. At all zenith angles from 15°-60° for the three separations 10 m, 25 m, and 40 m, the shower rate is slightly more from West than from East direction. This East-West asymmetry of extensive air showers is shown in Table III. In view of the very large statistical errors, and very poor angular resolution of the telescopes, it is felt better not to draw any definite conclusion. But it appears that there is some East-West asymmetry for extensive air showers also. From Table III it can be seen that for 10 m separation the asymmetry gradually increases from 15° to 60° zenith, whereas for 25 m, and 40 m, it reaches a maximum at 45° zenith and then comes down. To arrive at any conclusion regarding this East-West asymmetry of extensive air showers, more data are needed.

CONCLUSION

At moderate latitudes and mountain altitudes the geomagnetic field has a considerable and well detectable influence on the density distribution of extensive

air showers. The percentage asymmetry between the shower rates from E-W and N-S increases not only with the separation of the two telescopes but also with the zenith angle at which the telescopes are inclined. There appears to be 5 to 10% East-West asymmetry also for Extensive air showers.

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ON FERMION LOOPS OF TWO VERTICES

B. DEO

PHYSICS DEPARTMENT, RAVENSHAW COLLEGE, CUTTACK

(Received, December 10, 1959)

ABSTRACT. The imaginary part of the retarded matrix element for a closed loop of two vertices has been deduced by perturbation theory. It has been used to evaluate the photon and meson vacuum polarisation effects by assuming dispersion relations. Some difficulties regarding the mesic vacuum polarisation have been shown to be removed by considering the vertex correction.

The formulæ have been applied to deduce the decay rates of some fundamental particles and the results obtained are in good agreement with experiments.

INTRODUCTION

Much interest is attached to explain the decay of fundamental particles by weak universal fermi interaction and the known strong/medium strong interactions. In most of the decay processes, a closed loop has to be inserted in Feynman diagram to bring in the four-fermion vertex, a convenient example being the charged pion decay. Since the decay probability is proportional to the weak coupling constant (10^{-14} n. u.) squared, one would expect that a straightforward perturbation analysis using Dyson's S -Matrix expansion will give us the correct decay rates. However, the closed loops intervening the initial and final states bring in infinite constants. They cannot be renormalised in a formal way i.e. we cannot absorb the infinite constants as unobservable constants associated with mass and coupling constant. Most of the fundamental-particle-decay studies have, therefore, been confined to the ratio of decay rates and the like. And only very recently $\pi^{\pm} \rightarrow \mu^{\pm} + \nu(\bar{\nu})$ has been studied with considerable success by Goldberger and Trieman (1958).

To get rid of the infinite constants we shall calculate the imaginary part of the retarded matrix elements. This part is usually free from infinities and the real part can be evaluated from it by dispersion relations. In fact we shall show that the observable finite matrix elements can be unambiguously obtained from the imaginary part alone. Of course, one has to make a few subtractions, a procedure reminiscent of Pauli-Villars Regularisation Scheme.

MATRIX ELEMENT OF A LOOP

Let us take a loop with two vertices ($g_1\Gamma_1; g_2\Gamma_2$); g_1g_2 denoting the coupling strength and Γ_1 and Γ_2 may consist of matrices. Referring to the Feynman

diagram in Fig. 1, the contribution to the matrix element can be written as

$$F_{12}(k) \propto \frac{g_1 g_2}{i\pi^2} \int d^4 p \frac{\text{Tr}[\Gamma_1(ir, p-m)\Gamma_2(ir, p-k-m)]}{(p^2+m^2-i\epsilon)(p-k)^2+m^2-i\epsilon} \quad \dots (1)$$

where m is the mass of the fermion. Evaluating the trace and combining the denominators we get

$$F_{12}(k) \propto \frac{g_2 g_1}{i\pi^2} \int_0^1 dx \int d^4 p \frac{A p^2 + B_{\mu\nu} k_\mu k_\nu x(1-x) - \frac{1}{2}(C_\mu - D_\mu) i m k_\mu + E m^2}{(p^2 + k^2 x(1-x) + m^2 - i\epsilon)^2} \quad \dots (2)$$

where

$$\begin{aligned} A &= -\frac{1}{4} \text{sp}(\Gamma_1 \gamma_\mu \Gamma_2 \gamma_\mu) \\ B_{\mu\nu} &= \text{sp}(\Gamma_1 \gamma_\mu \Gamma_2 \gamma_\nu) \\ C_\mu &= \text{sp}(\Gamma_1 \gamma_\mu \Gamma_2) \\ D_\mu &= \text{sp}(\Gamma_1 \Gamma_2 \gamma_\mu) \\ E &= \text{sp}(\Gamma_1 \Gamma_2) \end{aligned} \quad \dots (2a)$$

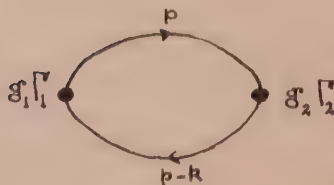


Fig. 1.

After partial integration over x , $F_{12}(k)$ can be written as (omitting g_1, g_2)

$$\begin{aligned} F_{12}(k) &= \frac{A}{i\pi^2} \int \frac{d^4 p}{p^2 + m^2 - i\epsilon} + \left\{ \frac{1}{6} B_{\mu\nu} k_\mu k_\nu - \frac{1}{3} A k^2 - \frac{1}{2} i m k_\mu (C_\mu - D_\mu) \right. \\ &\quad \left. + (E - A) m^2 \right\} \frac{1}{i\pi^2} \int \frac{d^4 p}{(p^2 + m^2 - i\epsilon)^2} + \int_0^1 dx \left\{ B_{\mu\nu} k_\mu k_\nu \left(\frac{x^2}{2} - \frac{x^3}{3} \right) \right. \\ &\quad \left. - A k^2 \frac{x^3}{3} - \frac{1}{2} (C_\mu - D_\mu) i m k_\mu x + (E - A) m^2 x \right\} \frac{k^2(1-2x)}{k^2 x(1-x) + m^2 - i\epsilon} \quad \dots (3) \end{aligned}$$

It is easily seen that the last term alone has an imaginary part, since

$$\frac{1}{a - i\epsilon} = \frac{P}{a} + i\pi \delta(a)$$

$$\therefore \quad \text{Im} . F_{12}(k^2) = +\pi \int_0^1 dx \, \delta(k^2 x(1-x) + m^2) \, k^2(1-2x) .$$

(expression in { } of Eqn. 3) ... (4)

In part of the retarded $H'_{12}(k^2)$ can be obtained by multiplying $\epsilon(k_0)$,

since
$$\Delta_F(k) = \frac{1}{k_\mu^2 + a^2 - i\epsilon} = \frac{\rho}{k^2 + a^2} + i\pi \delta(k^2 + a^2)$$

and
$$\Delta_R(k) \rightarrow \frac{1}{k^2 - (k_0 + i\epsilon)^2 + Q^2} = \frac{\rho}{k^2 + a^2} + i\pi \epsilon(k_0) \delta(k^2 + a^2)$$

with
$$\begin{aligned} \epsilon(k_0) &= +1 ; & k_0 &> 0 \\ &= 0 ; & k_0 &= 0 \\ &= -1 ; & k_0 &< 0 \end{aligned} \quad \dots (5)$$

Our task is now to integrate over x with proper care to the delta function.

To this end we write

$$\delta(k^2 x(1-x) + m^2) = \frac{1}{4m^2 x(1-x)} \delta\left(\frac{k^2}{4m^2} + \frac{4}{x(1-x)}\right) ,$$

and make the transformation $x = \frac{1+u}{2}$. The resulting integration is symmetrical and we get

$$\begin{aligned} \text{Im} . F_{12}^R(k^2) &= 4\pi\epsilon(k_0) \int_0^1 \delta\left(\frac{k^2}{4m^2} + \frac{1}{1-u^2}\right) \frac{k^2}{4m^2} \frac{u^2}{1-u^2} \left\{ \frac{1}{12} B_{\mu\nu} k_\mu k_\nu \left(1 + \frac{1-u^2}{2}\right) \right. \\ &\quad \left. + \frac{1}{6} A k^2 \left(\frac{1-u^2}{4} - 1\right) - \frac{1}{4} (C_\mu - D_\mu) i m k_\mu + \frac{1}{2} (E - A) m^2 \right\} du \quad \dots (6) \end{aligned}$$

Letting $z = \frac{1}{1-u^2}$ with the help of a theta function

$$\begin{aligned} \theta(x) &= 1 ; & x &> 0 \\ &= 0 ; & x &< 0 \end{aligned}$$

$$\text{Im} . F_{12}^R(k^2) = 4\pi\epsilon(k_0) \int_{-\infty}^{+\infty} \theta(z-1) \delta\left(\frac{k^2}{4m^2} + z\right) \frac{k^2}{4m^2} \frac{dz}{2z} \sqrt{1 - \frac{1}{z}} \left\{ \frac{1}{12} B_{\mu\nu} k_\mu k_\nu \right.$$

$$\left. \left(1 + \frac{1}{2z}\right) + \frac{1}{6} A k^2 \left(\frac{1}{4z} - 1\right) - \frac{1}{4} (C_\mu - D_\mu) i m k_\mu + \frac{1}{2} (E - A) m^2 \right\}$$

$$= - \frac{\pi}{2} \epsilon(k_0) 4\theta\left(-\frac{k^2}{4m^2} - 1\right) \sqrt{1 + \frac{4m^2}{k^2}} \left\{ \frac{1}{12} B_{\mu\nu} k_\mu k_\nu \left(1 - \frac{2m^2}{k^2}\right) \right.$$

$$\left. - \frac{1}{6} A k^2 \left(\frac{m^2}{k^2} + 1\right) - \frac{1}{4} i m k_\mu (C_\mu - D_\mu) + \frac{1}{2} (E - A) m^2 \right\} \quad \dots (7)$$

This, then, is the divergence-free retrate matrix element contribution and small correspond to the imaginary part of the total matrix element.

PHOTON VACUUM POLARISATION

The vacuum polarisation tensor $\Pi_{\mu\nu}$ of a photon for electron loop is given by

$$\Pi_{\mu\nu} = \frac{ie^2}{(2\pi)^4} \int d^4p \text{Tr.} \left\{ r_\mu \frac{ir \cdot p - k - m}{(p-k)^2 + m^2 - i\epsilon} \gamma_\nu \frac{ir \cdot p - m}{p^2 + m^2 - i\epsilon} \right\}$$

Thus

$$\Gamma_1 = \gamma_\mu; \quad \Gamma_2 = \gamma_\nu$$

$$A = 2g_{\mu\nu}; \quad B_{\lambda\nu} = 4(g_{\lambda\mu}g_{\sigma\nu} - g_{\mu\nu}g_{\lambda\sigma} + g_{\lambda\nu}g_{\mu\sigma}); \quad C_\mu = D_\mu = 0; \quad E = 4g_{\mu\nu}.$$

So we can write

$$\text{Im. } \pi^R_{\mu\nu}(k^2) = (k_\mu k_\nu - g_{\mu\nu} k^2) \text{Im. } \pi^R(k^2)$$

$$\text{Im. } \pi^R(k^2) = -\frac{\alpha}{3} \theta \left(-\frac{k^2}{4m^2} - 1 \right) \sqrt{1 + \frac{4m^2}{k^2}} \left(1 - \frac{2m^2}{k^2} \right) \epsilon(k_0) \quad \dots (8)$$

For large k^2 this imaginary part of $\pi^R(k^2)$ approaches a constant value, so the Hilbert transform will be logarithmically divergent, necessitating one subtraction.

$$\begin{aligned} \text{Re } \pi_f(k^2) &= \text{Re. } [\pi(k^2) - \pi(0)] = -\frac{\alpha}{3\pi} k^2 \rho \int_{4m^2}^{\infty} \frac{\left(1 + \frac{4m^2}{x} \right)^{\frac{1}{2}} \left(1 - \frac{2m^2}{x} \right)}{x(x-k^2)} dx \\ &= -\frac{\alpha}{3\pi} \left[\frac{5}{3} - \frac{4m^2}{k^2} - \left(1 - \frac{2m^2}{k^2} \right) \sqrt{1 + \frac{4m^2}{k^2}} \log \frac{\sqrt{1 + \frac{4m^2}{k^2}} + 1}{\sqrt{1 + \frac{4m^2}{k^2}} - 1} \right] \dots (9) \end{aligned}$$

which is the correct result.

MESIC VACUUM POLARISATION

Here $\Gamma_1 = \Gamma_2 = \gamma_5$ for a pseudoscalar coupling.

$$\begin{aligned} A &= -4; & B_{\mu\nu} &= 4g_{\mu\nu} \\ C_\mu &= D_\mu = 0; & E &= -4 \end{aligned}$$

Denoting the polarisation by $F(k^2)$ we have

$$\text{Im. part of } F(k^2) = -\frac{G^2}{4\pi} \theta \left(\frac{k^2}{4m^2} - 1 \right) \sqrt{1 + \frac{4m^2}{k^2}} \left(\frac{1}{8} k^2 \right)$$

This diverges linearly with $k^2 \rightarrow \infty$.

Hence the real part is quadratically divergent. Two subtractions are needed. The net observable effect is therefore contained in the integral

$$(G^2/4\pi) \cdot \frac{\rho}{\pi} \int_{4m^2}^{\infty} \frac{\sqrt{1 - \frac{4m^2}{x}} \frac{1}{8} x}{(x + \mu^2)^2 (x - k^2)} (k^2 + \mu^2)^2 dx. \quad \dots (11)$$

Evaluation of this integral will lead directly to the finite part of the meson propagation function.

EFFECT OF VERTEX CORRECTION ON THE CLOSED LOOP

In this section we shall study the correction due to the two vertices of the loop. Imaginary parts as given in equations (9) and (8) represent the effect of real pairs in the intermediate states. It should be obvious, therefore, the matrix elements of the vertex should be evaluated for real intermediate states; but for all values of k^2 subject to the condition that $k^2 \leq -4m^2$. For electrodynamics, this amounts to a negligible correction. But for mesons coupled to nucleons this amounts to a large correction. It should be noted that since the charge states of the nucleons are fixed, the correction for charged pion vertex is solely due to emission and absorption of π^0 mesons. The details of evaluation have been given in the Appendix. The result obtained is to replace γ_5 by a new function.

$$\Gamma_b = \frac{\gamma_5}{1 - \lambda \frac{k^2}{4m_p^2}} \quad \text{where } \lambda = \frac{g^2}{24\pi} \left(\frac{m_p}{\mu} \right)^2 \quad \dots (12)$$

$$g^2 = \frac{G^2}{4\pi}$$

Taking $g^2 = 15$; the coefficient $\lambda \simeq B$. This amounts to a large reduction to the real pair formation at the vertex. Even at threshold, $k^2 = -4m_p^2$; this is as large as 90%.

DECAY OF FUNDAMENTAL PARTICLES

We are now in a position to calculate the absolute decay rates which involve a close loop of which one vertex representing a strong γ_5 interaction. Let us take first the decay

$$\pi^+ \rightarrow \mu^+ + \nu$$

$$\pi^- \rightarrow \mu^- + \bar{\nu}$$

The Lagrangian density describing these decays is

$$\begin{aligned}
 \mathcal{L}_{int} = & f_A (\bar{\psi}_r (1 - \gamma_5) i \gamma_\lambda \gamma_5 \psi_\mu) (\bar{\psi}_n i \gamma_\lambda \gamma_5 \psi_p) \\
 & + f_V (\bar{\psi}_r (1 - \gamma_5) \gamma_\lambda \psi_\mu) (\bar{\psi}_n \gamma_\lambda \psi_p) + i \sqrt{2} G \bar{\psi}_n \gamma_5 \psi_p \phi_{\pi^+} \\
 & + i G \bar{\psi}_n \gamma_5 \psi_p \phi_{\pi^0} \\
 & + \text{Hermitian conjugate.} \quad \dots (13)
 \end{aligned}$$

Applying perturbation we shall take the Fermi coupling once and correct for the strong coupling vertex. First we note the vector coupling gives zero, due to the 'spur', so we have

$$\Gamma_1 = \gamma_5 : \quad \Gamma_2 = \gamma_\lambda \gamma_5$$

for the charged pion decay.

$$A = 0$$

$$B = 0$$

$$E = 0$$

$$C_\mu = -D_\mu = 4g_{\mu\lambda}.$$

Equation (7) takes the form

$$Im F_{12}(k^2) = 4im_p k_\lambda \pi \epsilon(k_0) \theta \left(-\frac{k^2}{4m_p^2} - 1 \right) \sqrt{1 + \frac{4m_p^2}{k^2}}$$

The factor ik_λ is to be contracted $i\gamma_\lambda k_\lambda$ with the free particle (μ, ν) spinors yielding m_μ , the mass of the muon. Thus

$$F(k^2) = 4im_p \cdot k_\lambda \pi \frac{\rho}{\pi} \int_{4m_p^2}^{\infty} \frac{\sqrt{1 - \frac{4m_p^2}{x}}}{x - k^2} dx \quad \dots (14)$$

which is log-divergent. However, if the correction at the vertex 1 is taken into account as given by (12),

$$F(k^2) = 4im_p k_\lambda \int_{4m_p^2}^{\infty} \frac{\sqrt{1 - \frac{4m_p^2}{X}}}{\left(1 + \frac{\lambda}{4m_p^2} X\right) (X - k^2)} dX \quad \dots (15)$$

which is convergent. We get

$$F(k^2) = im_p k_\lambda \frac{4m^2/k^2}{\lambda + \frac{4m^2}{k^2}} \cdot \left[(1 + \lambda)^{\frac{1}{2}} \ln \frac{(1 + \lambda)^{\frac{1}{2}} + 1}{(1 + \lambda)^{\frac{1}{2}} - 1} \right. \\ \left. - \left(1 - \frac{4m^2}{k^2} \right)^{\frac{1}{2}} \log \left| \frac{\left(1 - \frac{4m^2}{k^2} \right)^{\frac{1}{2}} + 1}{\left(1 - \frac{4m^2}{k^2} \right)^{\frac{1}{2}} - 1} \right| \right] \quad \dots \quad (16)$$

We shall frequently use this result in evaluating decay rates. For convenience we write

$$F(-\mu^2) = 8im_p k_\lambda G(-\mu^2) \quad \dots \quad (17)$$

where

$$G(-\mu^2) = \frac{1}{2} \frac{4m^2/\mu^2}{4m^2/\mu^2 - \lambda} \left[(1 + \lambda)^{\frac{1}{2}} \ln \frac{(1 + \lambda)^{\frac{1}{2}} + 1}{(1 + \lambda)^{\frac{1}{2}} - 1} \right. \\ \left. - \left(1 + \frac{4m^2}{\mu^2} \right)^{\frac{1}{2}} \ln \frac{\left(1 + \frac{4m^2}{\mu^2} \right)^{\frac{1}{2}} + 1}{\left(1 + \frac{4m^2}{\mu^2} \right)^{\frac{1}{2}} - 1} \right] \quad \dots \quad (17a)$$

We can estimate $G(-\mu^2)$ by noting

$$4m^2/\mu^2 \gg \lambda > 1.$$

Expanding the logarithms and retaining the first leading term, we obtain

$$G(-\mu^2) = \frac{1}{1 + \lambda} \quad \dots \quad (18)$$

which depends only on the damping at the vertex.

Returning to the calculation of the decay rate we note the matrix element is in understandable notation

$$\langle \mu^+, \bar{\nu} | M | \pi^+ \rangle = \frac{\sqrt{2} G_A}{(2\pi)^{3/2}} \cdot \frac{1}{\sqrt{2\omega_\pi}} \cdot \sqrt{\frac{m_\mu}{e_\mu e_\nu}} \bar{u}_\mu(p_\mu)(i\gamma_5 k_\pi)(1 + \gamma_5)v_\nu(p_\nu) \\ 8m_p \pi^2 G(-\mu^2). \quad \dots \quad (19)$$

with four momentum conservation.

This leads to the following decay rate in a familiar way,

$$\omega = \frac{m_\pi}{2\pi^4} \left(\frac{m_\mu}{m_\pi} \right)^2 \left(\frac{m_p}{m_\pi} \right)^2 \left(1 - \frac{m_\mu^2}{m_\pi^2} \right)^2 \left(\frac{G^2}{4\pi} \right) \cdot (g_A m_\mu^2)^2 [G(-\mu^2)]^2 \quad \dots (20)$$

If we take $G^2/4\pi = 15$ and if we adopt for g_A the value of the Gomow-Teller coupling constant, we then find from the known pion life time that

$$G(-\mu^2) = 0.13, \quad \dots (21)$$

whereas equation (18) gives

$$G(-\mu^2)|_{theory} = 0.11, \quad \dots (22)$$

Thus the agreement can be considered extremely satisfactory. We emphasize again the influence of vertex damping as has been pointed out by Goldberger and Triemann (1958); they have, however, made a phase-shift analysis whereas we have just corrected for the vertex.

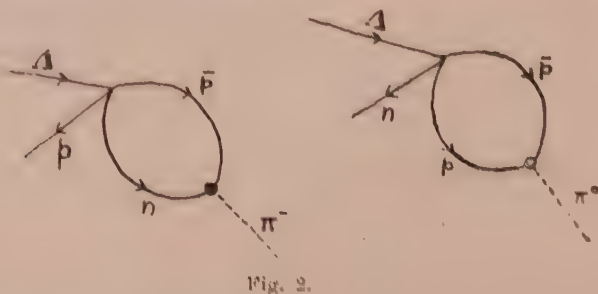
One would naturally be tempted to apply similar considerations to $K \rightarrow \mu + \nu$ decays. Ignoring strangeness considerations, the decay rate is not very different from what one would expect. The value of λ , however, is about 10 times smaller, and the full expression (17a) is to be used. One cannot compare the life time with experiment since there are many channels of decay for the K -meson.

We shall extend our calculations to the decay modes

$$\Delta \rightarrow \begin{cases} p + \pi^- \\ n + \pi^0 \end{cases} \quad \dots (23a)$$

$$\dots (23b)$$

The simplest possible graphs leading to pionic Δ -decay are shown in Fig. 2.



The decay rates are

$$\begin{aligned} \omega(\Delta \rightarrow p + \pi^-) &= g_A^2 \frac{G^2}{4\pi} \frac{1}{2\pi^4} [G(-\mu^2)]^2 m_p^2 (m_\Delta - m_p)^2 (m_\Delta^2 + m_p^2 - \mu^2) \frac{1}{m_\Delta^3} \\ &\cdot [(m_\Delta - m_p)^2 - \mu^2]^3 [(m_\Delta + m_p)^2 - \mu^2]^3 \\ &\frac{\omega(\Delta \rightarrow p + \pi^0)}{\omega(\Delta \rightarrow p + \pi^-)} = 0.5. \end{aligned}$$

which is very near the observed ratio 0.59 ± 0.07 . In deducing this we have tacitly assumed that (p, p) are the only intermediate virtual pair for the decay involving the neutral meson.

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The author wishes to record his thanks to his colleagues Dr. T. Pradhan and S. P. Misra for many interesting discussions.

APPENDIX

Here we shall deduce the correction to a vertex as shown in Fig. 3, so that all the corrections due to pulling out the vertex in the direction of the boson line are accounted for.

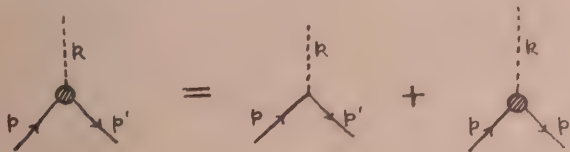


Fig. 3.

The function Γ_5 for such processes as depicted is

$$\Gamma_5 = \gamma_5 + \frac{iG^2}{(2\pi)^4} \int d^4l \cdot \frac{\gamma_5(ir \cdot p - l - m_p)\Gamma_5(ir \cdot p' - l + m_p)\gamma_5}{(l^2 + \mu^2)((p-l)^2 + m_p^2)((p'-l)^2 + m_p^2)}$$

Since Γ_5 is proportional to odd powers of γ_5 we can anticommute it through the γ -matrices. The denominators can be combined by the well-known Feynman method and we obtain,

$$\Gamma_5 = \gamma_5 + \frac{iG^2}{(2\pi)^4} 2 \int_0^1 dx \int_0^x dy \int d^4l \cdot \frac{(ir \cdot p - l + m_p)\Gamma_5(ir \cdot p' - l + m_p)}{[(l - px - ky)^2 + a^2]^3}$$

where

$$a^2 = m_p^2 x^2 + \mu^2(1-x-y)(x-y) + (p^2 + m^2)(x-y)(1-x) + (p'^2 + m^2)(1-x)y + (k^2 + \mu^2)y(x-y)$$

Shifting the origin of '1' integration, we can write,

$$\Gamma_5 = \gamma_5 + \frac{iG^2}{(2\pi)^4} 2 \int_0^1 dx \int_0^x dy \int d^4l \cdot \frac{K - (l^2 - m_p^2 x - \mu^2 y)(x-y)\Gamma_5}{(l^2 + a^2)^3}$$

where,

$$K = -(ir \cdot p' + m_p) \Gamma_5(ir \cdot p + m_p - ir \cdot pX - ir \cdot kY) \\ - (ir \cdot pX + ir \cdot kY) \Gamma_5(ir \cdot p - m_p) - (p^2 - m_p^2)x(x-y) \Gamma_5 - (p'^2 + m_p^2)xy \Gamma_5 \\ - (k^2\mu^2)Y(X-Y)\Gamma_5.$$

One can now renormalize in the conventional way, by writing,

$$\Gamma_5(p', p) = \gamma_5(1+L) + \Gamma_{5f}(p', p)$$

where L is determined by the equation

$$\Gamma_{5f}(p, p) = 0 \quad \text{for } ir \cdot p' = ir \cdot p = -m_p.$$

For our case, $\Gamma_{5f}(p', p) = \Gamma_5 I(k^2)$ with $ir \cdot p' = ir \cdot p = -m_p$, but for arbitrary value of k^2 .

Performing the necessary '1' integration and estimating the major contributions from y and x integrations, we obtain the equation (12) given in the text.

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THERMAL CONDUCTIVITY AND EUCKEN-TYPE FACTOR FOR THE BINARY MIXTURES H-He, H-Ne, H-Kr and H-Xe

A. K. BARUA

INDIAN ASSOCIATION FOR THE CULTIVATION OF SCIENCE, CALCUTTA-32

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ABSTRACT. In order to test the recent formulae for the thermal conductivity of polyatomic gas mixtures, the thermal conductivity of H_2 -He, H_2 -Ne, H_2 -Kr and H_2 -Xe mixtures have been measured at 30°C and 45°C by using the thick-wire-variant of the hot-wire method. The experimental values of the thermal conductivity of the pure gases and their binary mixtures is lower than those given by Hirschfelder's theory based on the local chemical equilibrium assumption. It has been suggested that this discrepancy between theory and experiments at the temperatures under consideration is due to the non-validity of the condition of local chemical equilibrium. Apart from this drawback Hirschfelder's theory has been found to represent the concentration dependence of the thermal conductivity of polyatomic gas mixtures quite satisfactorily. The more rigorously derived formula of Hirschfelder has been found to represent the thermal conductivity of gas mixtures better than the approximate equation of Mason and Saxena.

1. INTRODUCTION

The problem of heat transfer in multicomponent mixtures of monatomic and polyatomic gases has recently attracted considerable attention. Though Curtiss and Hirschfelder (1949) has obtained expressions for the thermal conductivity of multicomponent mixture of monatomic gases by an extension of the Chapman-Enskog treatment for a binary mixture which is correct to the first approximation, their formula requires too much laborious calculations. In an attempt to overcome this difficulty, Mason (1958), Curtiss and Muckenfuss (1958) and Brokaw (1958) have obtained simpler expressions for the thermal conductivity of multicomponent mixtures of monatomic gases. The difficulty in treating the monatomic gases is only computational but the problem of heat transfer in polyatomic gases and gas mixtures is much more interesting as in this case the exchange of energy between the translational and the internal energies of the molecules need be considered. Eucken (1913) first suggested a correction to the thermal conductivity of polyatomic gases which was based on simple intuitive arguments whose inadequacy was later pointed out by several workers (Chapman and Cowling, 1952; K. Schafer, 1943). Recently, Hirschfelder (1957a) has obtained an expression for the thermal conductivity of a pure polyatomic gas by a formal

treatment in which the molecules in different states of excitation are treated as separate chemical species in local chemical equilibrium. The treatment for a pure polyatomic gas has been extended by Hirschfelder (1957b) to the case of the polyatomic gas mixtures. Mason and Saxena (1958) have made a number of approximations to simplify Hirschfelder's formula for the mixture conductivities. As accurate data on the thermal conductivity of gas mixtures are not extensive elaborate comparison of the experimental data with the recent theories cannot be made. Recently, Srivastava and his co-workers (1959, 1960a, 1960b) have measured the thermal conductivity of a number of binary mixtures of diatomic and monatomic gases and compared their data with the theory. In order to test further the expression for the thermal conductivity of gas mixtures and also to verify the suggestion of the non-validity of the condition of local chemical equilibrium in the present investigation the paper values of thermal conductivity of $\text{H}_2\text{-He}$, $\text{H}_2\text{-Ne}$, $\text{H}_2\text{-Kr}$ and $\text{H}_2\text{-Xe}$ mixtures at 30°C and 45°C have been reported.

2. EXPERIMENT

The apparatus and the procedure adopted for the experiment are similar to those described by Srivastava and Barua (1960) and the constants of the conductivity cell are given in Table I.

TABLE I
Constants of the conductivity cell

	At 30°C	At 45°C
Length of the cell wire ($2l$)	5.9978 cm.	5.9987 cm.
Radius of the cell wire (r_1)	0.00500 „	0.00500 „
Internal diameter of the tube ($2r_2$)	0.3048 „	0.3048 „
External diameter of the tube ($2r_3$)	0.5915 „	0.5915 „
Resistance of the cell wire (R_0)	0.83518 Ω	0.88012 Ω
Temperature coefficient of resistance α of the platinum wire	0.00360 $^\circ\text{C}^{-1}$	0.00358 $^\circ\text{C}^{-1}$
Thermal conductivity λ of the platinum wire in cal. cm^{-1} , sec^{-1} , $^\circ\text{C}^{-1}$	0.167	0.168
Cell constant ($1-C$)	0.9942	0.9941

As shown by Kannuluik and Martin (1934) the solution of the differential equation for heat flow is given by

$$f(\beta l) = \frac{1}{(\beta l)^2} \left(1 - \frac{\tanh \beta l}{\beta l} \right) = \frac{2\pi r_1^2 \lambda J(R - R_0)}{R_0^2 \alpha l^2} \quad \dots \quad (1)$$

with

$$\beta^2 = \frac{2h}{r_1 \bar{\lambda}} - \frac{I^2 R_0 \alpha_1}{2\pi r_1^2 \lambda J l}, \quad h = \frac{Ku}{r_1 \ln(r_2/r_1)} \quad \dots (2)$$

where R is the resistance of the wire when a current of I amp. is flowing through it, R_0 is the resistance of the cell wire at the bath temperature for $I = 0$, λ , K_u are the thermal conductivities of the wire and the gas respectively.

In Table II are shown the observations taken for H_2 -He mixtures at 30°C which may serve as an example for the observations taken for other mixtures. In the Tables K_u has been calculated from Eq. (1) and (2), K_u' is the value of K_u reduced to the bath temperature and K' is the value of the conductivity when temperature jump and wall effect are corrected for and K is the value obtained after correcting for the asymmetry in the construction of the cell given by the relation $K = K'(1 - C)$. In Tables III and IV are given the observed values of the thermal conductivity of the mixtures H_2 -He, H_2 -Ne, H_2 -Kr and H_2 -Xe at 30°C and 45°C which are plotted in Figs. 1 and 2,

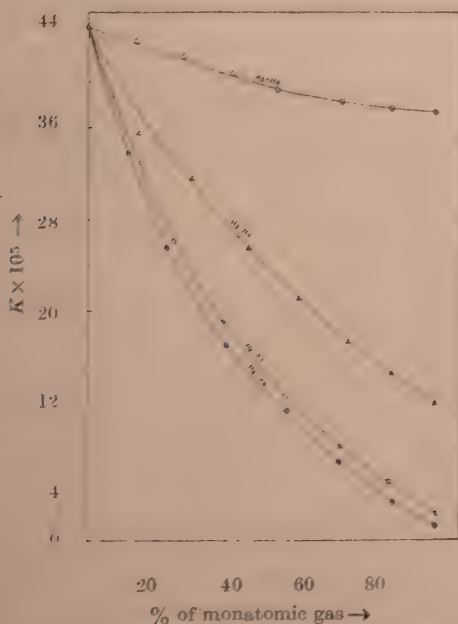


Fig. 1. Thermal conductivity K of H_2 -He, H_2 -Ne, H_2 -Kr and H_2 -Xe mixtures of different compositions at 30°C .

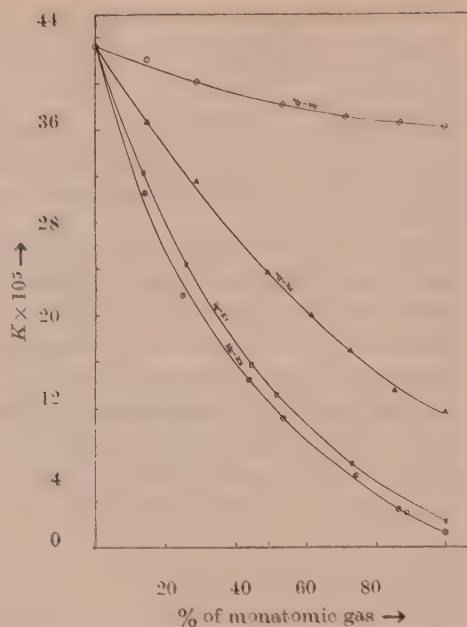


Fig. 2. Thermal conductivity K of H_2 -He, H_2 -Ne, H_2 -Kr and H_2 -Xe mixtures of different compositions at 45°C .

TABLE II

Thermal conductivity K of H_2 -He mixtures in
cal. $\text{cm}^{-1}\text{sec}^{-1}.\text{C}^{-1}$ at 30°C

% of He	I in m.u.	$R-R_0$ in $m\ \Omega$	$K_H \times 10^5$	$K_H' \times 10^5$	$K' \times 10^5$	$K \times 10^5$
100	208.42	6.247	36.89	36.79	36.49	36.32
87.13	207.68	6.023	37.24	37.14	36.84	36.63
71.36	209.78	6.040	37.88	37.78	37.39	37.17
53.28	214.62	6.125	39.06	38.95	38.58	38.36
45.62	213.75	6.008	39.59	39.49	39.18	38.95
28.91	212.31	5.690	41.25	41.13	40.75	40.52
14.64	210.16	5.323	43.24	43.12	42.72	42.47
0	213.48	5.289	44.99	44.89	43.49	43.20

TABLE III

 Thermal conductivity K of H-He, H-Ne, H-Kr and H-Xe mixtures at 30°C

Gas Mixture	H ₂ -He		H ₂ -Ne		H ₂ -Kr		H ₂ -Xe	
	% of He	$K \times 10^5$	% of Ne	$K \times 10^5$	% of Kr	$K \times 10^5$	% of Xe	$K \times 10^5$
100	36.32		100	11.65	100	2.256	100	1.261
87.13	36.63		85.61	13.52	88.62	3.011	86.24	3.374
71.36	37.17		72.83	17.04	73.26	7.254	74.31	6.205
53.28	38.36		61.31	20.01	51.39	13.31	54.62	11.15
45.62	38.95		48.93	23.70	44.62	15.82	43.79	14.40
28.91	40.52		28.93	31.62	25.84	24.39	25.68	21.78
14.64	42.47		14.82	36.65	13.63	32.27	14.31	30.62
0	43.20		0	43.16	0	43.91	0	43.16

TABLE IV

 Thermal conductivity K of H-He, H-Ne, H-Kr and H-Xe mixtures at 45°C

Gas Mixture	H-He		H-Ne		H-Kr		H-Xe	
	% of He	$K \times 10^5$	% of Ne	$K \times 10^5$	% of Kr	$K \times 10^5$	% of Xe	$K \times 10^5$
100	37.31		100	12.00	100	2.347	100	1.322
86.75	37.66		86.71	14.61	85.62	5.074	87.45	3.283
73.21	38.31		74.86	17.31	72.41	8.208	72.31	6.945
54.62	39.25		60.41	21.16	56.39	12.57	57.62	11.48
41.36	70.40		46.54	25.55	38.64	16.04	40.39	17.10
27.81	42.35		29.83	31.52	24.31	26.06	22.61	25.80
14.69	44.03		14.62	35.05	15.42	33.01	12.86	33.78
0	44.75		0	44.84	0	44.79	0	44.77

3. COMPARISON WITH THEORY

The simple Eucken (1913) expression for the thermal conductivity of a pure polyatomic gas may be written as

$$K = \frac{\eta}{M} [f_{trans} C_{V_{trans}} + f_{int} C_{V_{int}}], \quad \dots \quad 3)$$

where K is the thermal conductivity, η the viscosity, M the molecular weight, $C_{v_{trans}}$, $C_{v_{int}}$ are the molar specific heats at constant volume corresponding to the translational and the internal degrees of freedom. $f_{trans}=2.5$ and f_{int} indicate the transfer factors for the translational and the internal motions respectively. For simplicity Eucken put $f_{int}=1$, so that Eq. (3) becomes

$$K = K_{mon} [(4/15)C_v/R + 3/5]. \quad \dots (4)$$

where K_{mon} is the thermal conductivity of the gas when it is taken to be monatomic. Actually, however, internal energy is transported by a diffusion mechanism (Chapman and Cowling, 1952; Schäfer, 1943) so that $f_{int}=1$ should be replaced by $f_{int}=\rho D/\eta$ (where ρ is the density, D the self-diffusion coefficient and η the viscosity) and Eq. (4) becomes,

$$K = \frac{\eta}{M} \left[2.5 C_{v_{trans}} + (\rho D/\eta) C_{v_{int}} \right] \quad \dots (5)$$

Hirschfelder (1957a) has obtained the following expression for the thermal conductivity of a pure polyatomic gas by considering the molecules in different states of excitation as separate chemical species which are in local chemical equilibrium,

$$K/K_{mon} = (1-\delta_f) + \delta_f \rho DC_p/C_{pf}. \quad \dots (6)$$

where $\delta_f = \rho DC_{pf}/K_{mon}$, $C_{pf} = 5R/2$. The values of δ_f has been tabulated for several molecular models and it has been shown that δ_f varies very little with temperature and it is possible to assign to δ_f an average value of 0.885 so that Eq. (6) becomes

$$K/K_{mon} = 0.354 C_v/R + 0.469 \quad \dots (7)$$

By extending the treatment applied to a pure polyatomic gas Hirschfelder (1957b) has obtained the following expression for the thermal conductivity of a binary mixture of polyatomic gases

$$K_{mix} = K_{mix(mon)} + [K_1 - K_{1mon}] [1 + (x_2/x_1)(D_{11}/D_{12})]^{-1} \quad \dots (8) \\ + [K_2 - K_{2mon}] [1 + (x_1/x_2)(D_{22}/D_{12})]^{-1}$$

where K_1 , K_2 are the thermal conductivities, D_{11} , D_{22} are the coefficients of self-diffusion and x_1 , x_2 are the molefractions for the components 1 and 2 of the mixture. D_{12} represents the coefficient of inter-diffusion.

In the present case the gas mixture consists of a diatomic gas denoted by the subscript 1 and a monatomic gas denoted by the subscript 2 so that Eq. (8) becomes

$$K_{mix} = K_{mix(mon)} + [K_1 - K_{1mon}] [1 + (x_2/x_1)(D_{11}/D_{12})]^{-1} \quad \dots (9)$$

The calculation of K_{mix} from Eq. (8) involves laborious computation and the knowledge of force laws between the molecules is necessary which is not easily available. Mason and Saxena (1958) have however tried to simplify Eq. (8) by a number of approximations and their formula may be written as,

$$K_{mix} = \sum_{i=1}^n K_i \left[1 + \sum_{\substack{j=1 \\ i \neq j}}^n G_{ij} \frac{x_j}{x_i} \right]^{-1}, \quad \dots (10)$$

with

$$G_{ij} = \frac{1.065}{2\sqrt{2}} \left(1 + \frac{M_i}{M_j} \right)^{-\frac{1}{2}} \left[1 + \left(\frac{K_i^0}{K_j^0} \right)^{\frac{1}{2}} \left(\frac{M_i}{M_j} \right)^{1/4} \right]^2 \quad \dots (11)$$

where x_i, x_j are the molefractions, M_i, M_j the molecular weights of the components i and j respectively, K_i^0, K_j^0 are the thermal conductivities when the gases are treated as monatomic and are related to the viscosities η_i, η_j by the relation

$$K_i^0/K_j^0 = \frac{\eta_i M_j}{\eta_j M_i} \quad \dots (12)$$

When η_i and η_j are known experimentally, K_i^0/K_j^0 may be calculated from Eq. (12). In case the experimental viscosity data are not available, specific heat data may be used to obtain K_i^0/K_j^0 . In order to compute K_{mix} from Eq. (10) the experimental values of K_i and K_j are to be used.

For comparing with the theory K_{mon} was calculated to the first approximation on the Lennard-Jones (12 : 6) model from the expression

$$K_{1 mon} = \frac{1989.1 \sqrt{T/M}}{\Omega^{(2,2)*}(T^*) \sigma^2} \quad \dots (13)$$

where $\Omega^{(2,2)*}(T^*)$ is a collision integral which has been tabulated (Hirschfelder, Curtiss and Bird, 1954) as a function of $T^* = kT/\epsilon$, σ and ϵ/k being the potential parameters in Å and °K respectively. When K_{mon} is known, the experimental value of the Eucken factor K_{exp}/K_{mon} can be calculated. In order to calculate K/K_{mon} from Hirschfelder's Eq.(6), δ_f was taken from the tables (Hirschfelder 1957a) and specific heat data were obtained from the recent Tables published by the National Bureau of Standards (1955). By knowing K_{exp}/K_{mon} , the experimental value of δ_f may be calculated from Eq.(6) and the corresponding value of f_{int} from the relation $f_{int} = 3/2\delta_f$. Similar calculations were done for the data obtained by other workers. The results of these calculations are indicated in Table V.

In order to calculate K_{mix} from Eq. (9), $K_{mix(mon)}$, D_{11} , D_{12} were calculated on the Lennard-Jones (12 : 6) model from the expressions obtained on the Chapman-Enskog theory (Hirschfelder, Curtiss and Bird, 1954). The force constants were taken as those determined from viscosity data except in the case of Kr for

which the force constants determined by Saxena (1957) from thermal conductivity data were used. The results of these calculations are given in Tables VI- XIII.

TABLE V
Eucken factor and f_{int} for H_2

T°K	K_{exp} given by	Eucken factor			$f_{int} = \frac{2}{3} \delta_f$	
		K_{exp} K_{mon}	K/K_{mon} from Eq. (6)	K/K_{mon} from Eq. (4)	From expt.	From Tables
303.2	Present Work	1.312	1.343	1.259	1.121	1.330
318.2	-do-	1.314	1.348	1.261	1.162	1.331
273.2	Koyos (1952)	1.289	1.326	1.251	1.155	1.328
300.2	Johnston & Grilly (1946)	1.286	1.345	1.259	1.103	1.330
320.2	-do-	1.288	1.348	1.262	1.112	1.331
311.2	Srivastava & Srivastava (1959).	1.296	1.344	1.259	1.142	1.331

In column 3, K_H is the value of K_{mix} calculated from Eq. (9) with the theoretical value of δ_f and K'_H in column 4 are those obtained with the experimental value of δ_f . For calculating K_{mix} from Eq. (10), viscosity data were used for H_2 -He, and H_2 -Ne and specific heat data for H_2 -Kr and H_2 -Xe. These calculated values are indicated as K_{MS} in column 5 of Tables VI-XIII. Columns 6 and 7 give the values of the Eucken-type factors for the mixtures $K_{exp}/K_{mix(mon)}$ and $K'_H/K_{mix(mon)}$. The experimental values of K_{mix} were read from suitable interpolation graphs.

An interesting test of the algebraic form of Hirschfelder formula for the gas mixture may be made in the following way :

Eq.(9) may be written as

$$K_{mix} - K_{mix(mon)} = \frac{K_1 - K_{1 mon}}{1 + (x_2/x_1)(D_{11}/D_{12})} \quad \dots (14)$$

or $y = mx + C$

where $y = 1/(K_{mix} - K_{mix(mon)})$; $x = x_2/x_1$; $m = (D_{11}/D_{12})/(K_1 - K_{1 mon})$;

$$C = 1/K_1 - (K_{1 mon})$$

so that a plot of y vs x should be a straight line. The y - x values for the different gas mixtures have been given in columns 8 and 9 of the Tables VI-XIII and

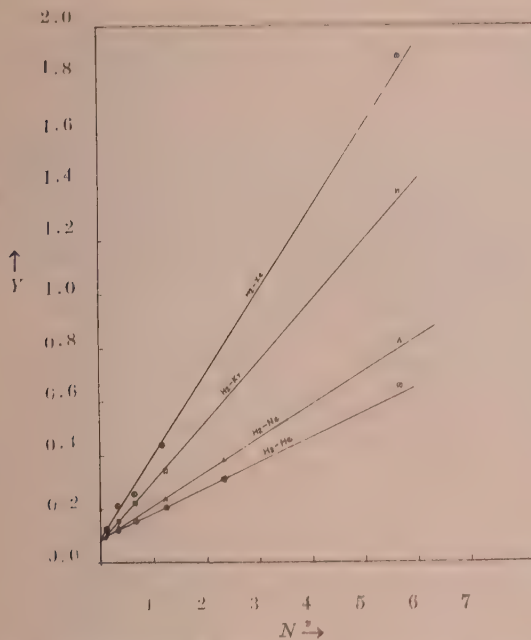


Fig. 3. x - y graphs for H_2 -He, H_2 -Ne, H_2 -Kr and H_2 -Xe at 30°C .

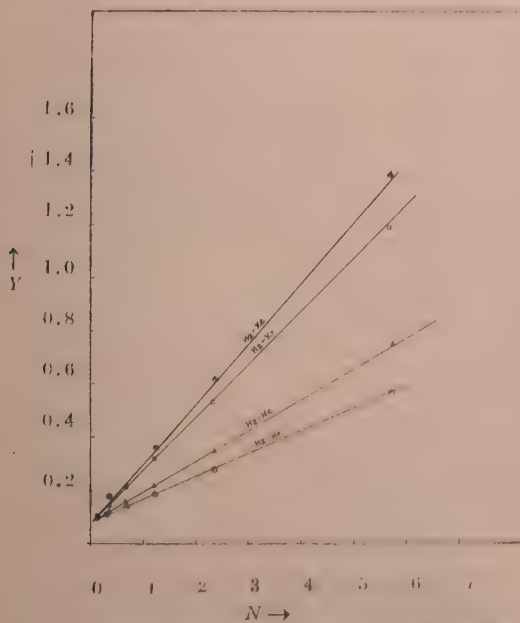


Fig. 4. x - y graphs for H_2 -He, H_2 -Ne, H_2 -Kr and H_2 -Xe at 45°C .

are plotted in Figs. 3 and 4. The intercept on the y -axis gives the value of K_1 and the slope gives the value of D_{11}/D_{12} from which D_{12} can be obtained by knowing D_{11} .

TABLE VI
Thermal conductivity and Eucken-type factor for H_2 -He
mixture at $30^\circ C$

% of He	$K_{exp} \times 10^5$	$K_H \times 10^5$ from Eq.(9)	$K'_H \times 10^5$ from Eq.(9)	$K_{MS} \times 10^5$ from Eq.(10)	K_{exp} $K_{mix(mon)}$	K'_H $K'_{mix(mon)}$	y	x
100	36.32	36.32	36.32	36.32	1.000	1.000	.....	.....
85	36.80	37.12	37.06	37.01	1.038	1.046	0.719	5.666
70	37.44	37.58	37.45	37.86	1.096	1.096	0.306	2.333
55	38.29	38.55	38.36	38.88	1.145	1.148	0.206	1.223
40	39.45	39.80	39.55	40.05	1.195	1.199	0.155	0.667
25	40.96	41.37	41.06	41.39	1.246	1.249	0.123	0.333
10	42.73	43.25	42.88	42.88	1.293	1.298	1.103	0.111
0	43.20	44.42	43.20	43.20	1.312	1.312	.....	.....

TABLE VII
Thermal conductivity and Eucken-type factor for H_2 -He
mixture at $45^\circ C$

% of He	$K_{exp} \times 10^5$	$K_H \times 10^5$ from Eq.(9)	$K'_H \times 10^5$ from Eq.(9)	$K_{MS} \times 10^5$ from Eq.(10)	K_{exp} $K_{mix(mon)}$	K'_H $K'_{mix(mon)}$	y	x
100	37.31	37.31	37.31	37.31	1.000	1.000	.....	.....
85	37.92	38.07	37.95	38.13	1.045	1.046	0.599	5.667
70	38.60	38.73	38.47	39.11	1.105	1.101	0.275	2.333
55	39.55	39.77	39.62	40.25	1.157	1.160	0.186	1.223
40	40.88	41.12	40.82	41.56	1.212	1.210	0.140	0.667
25	42.57	42.79	42.47	43.03	1.264	1.261	0.113	0.333
10	44.46	44.89	44.56	44.57	1.304	1.307	0.097	0.111
0	44.75	46.03	44.75	44.75	1.314	1.314	.....	.....

TABLE VIII

Thermal conductivity and Eucken-type factor for H₂-Ne mixture at 30°C

% of Ne	$K_{exp} \times 10^5$	$K_H \times 10^5$ from Eq.(9)	$K'_H \times 10^5$ from Eq.(9)	$K_{MS} \times 10^5$ from Eq.(10)	K_{exp} $K_{mix(mon)}$	K'_H $K_{mix(mon)}$	y	x
100	11.65	11.65	11.65	11.65	1.000	1.000	.....	.....
85	14.25	14.25	14.23	15.52	1.081	1.080	0.822	5.667
70	17.74	17.97	17.83	20.07	1.174	1.180	0.380	2.333
55	21.80	22.01	21.80	24.69	1.240	1.240	0.237	1.223
40	26.58	26.78	26.49	28.68	1.287	1.282	0.169	0.667
25	32.24	32.47	32.09	34.71	1.315	1.309	0.129	0.333
10	38.88	39.18	38.71	40.02	1.319	1.316	0.104	0.111
0	43.16	44.42	43.16	43.16	1.311	1.311	.....	.....

TABLE IX

Thermal conductivity and Eucken-type factor for H₂-Ne mixture at 45°C

% of Ne	$K_{exp} \times 10^5$	$K_H \times 10^5$ from Eq.(9)	$K'_H \times 10^5$ from Eq.(9)	$K_{MS} \times 10^5$ (Eq.10)	K_{exp} $K_{mix(mon)}$	K'_H $K_{mix(mon)}$	y	x
100	12.00	12.00	12.00	12.00	1.000	1.000	.....	.....
85	14.94	15.06	15.00	16.10	1.098	1.102	0.752	5.667
70	18.59	18.68	18.57	20.91	1.185	1.183	0.345	2.333
55	22.71	22.87	22.69	25.81	1.246	1.245	0.223	1.223
40	27.81	28.00	27.74	30.03	1.292	1.289	0.159	0.667
25	33.52	33.72	33.39	36.43	1.321	1.316	0.123	0.333
10	40.56	40.68	40.37	42.09	1.340	1.334	0.0971	0.111
0	44.84	46.03	44.84	44.84	1.317	1.317	.....	.....

TABLE X

Thermal conductivity and Eucken-type factor for H₂-Kr mixture
at 30°C

% of Kr	$K_{exp} \times 10^5$	$K_H \times 10^5$ from Eq. (9)	$K'_H \times 10^5$ from Eq. (9)	$K_{MS} \times 10^5$ from Eq. (10)	K_{exp} $K_{mix(mon)}$	K'_H $K_{mix(mon)}$	y	x
100	2.256	2.256	2.256	2.265	1.000	1.000	.....	.....
85	4.602	4.903	4.876	5.324	1.168	1.216	1.390	5.667
70	9.016	8.299	8.240	8.901	1.264	1.299	0.597	2.333
55	12.20	12.53	12.43	13.36	1.311	1.336	0.345	1.223
40	17.62	17.95	17.80	18.96	1.343	1.338	0.224	0.667
25	24.84	25.13	24.72	26.18	1.345	1.344	0.155	0.333
10	35.02	35.25	34.97	35.75	1.346	1.344	0.111	0.111
0	43.21	44.42	43.88	43.21	1.312	1.312	.....	.....

TABLE XI

Thermal conductivity and Eucken-type factor for H₂-Kr mixture
at 45°C

% of Kr	$K_{exp} \times 10^5$	$K_H \times 10^5$ from Eq. (9)	$K'_H \times 10^5$ from Eq. (9)	$K_{MS} \times 10^5$ from Eq. (10)	K_{exp} $K_{mix(mon)}$	K'_H $K_{mix(mon)}$	y	x
100	2.347	2.347	2.347	2.347	1.000	1.000	.....	.....
85	5.160	5.281	5.246	5.510	1.195	1.214	1.191	5.667
70	8.600	8.775	8.695	9.310	1.280	1.294	0.531	2.333
55	12.86	13.15	13.01	13.99	1.317	1.334	0.322	1.223
40	18.31	18.74	18.54	19.83	1.350	1.352	0.217	0.667
25	25.66	26.04	25.76	27.35	1.351	1.358	0.156	0.333
10	36.46	37.60	36.59	37.32	1.355	1.359	0.105	0.111
0	44.79	46.03	44.79	44.79	1.315	1.315	.....	.....

TABLE XII

Thermal conductivity and Eucken-type factor for H₂-Xe mixture at 30°C

% of Xe	$K_{exp} \times 10^5$	$K_H \times 10^5$	$K'_H \times 10^5$	$K_{MS} \times 10^5$	K_{exp}	K'_H	y	z
		from Eq.(9)	from Eq.(9)	from Eq.(10)	$K_{mix(mon)}$	$K_{mix(mon)}$		
100	1.261	1.261	1.261	1.261	1.000	1.000	.....	.....
85	3.745	3.807	4.779	3.722	1.176	1.231	1.898	5.667
70	6.812	6.864	6.803	6.787	1.318	1.316	0.814	2.333
55	10.61	10.77	10.67	10.71	1.340	1.347	0.398	1.223
40	15.81	16.14	15.99	15.91	1.338	1.353	0.253	0.667
25	21.68	21.92	21.74	23.85	1.283	1.287	0.211	0.333
10	33.49	33.79	33.74	34.22	1.347	1.346	0.155	0.111
0	43.16	44.42	43.16	43.16	1.311	1.311	.....	.....

TABLE XIII

Thermal conductivity and Eucken-type factor for H₂-Xe mixture at 45°C

% of Xe	$K_{exp} \times 10^5$	$K_H \times 10^5$	$K'_H \times 10^5$	$K_{MS} \times 10^5$	K_{exp}	K'_H	y	z
		from Eq.(9)	from Eq.(9)	from Eq.(10)	$K_{mix(mon)}$	$K_{mix(mon)}$		
100	1.322	1.322	1.322	1.322	1.000	1.000	.....	.....
85	3.936	3.988	3.931	3.916	1.245	1.243	1.293	5.667
70	7.062	7.191	7.066	7.142	1.315	1.316	0.590	2.333
55	11.05	11.27	11.06	11.26	1.345	1.346	0.353	1.223
40	16.31	16.71	16.40	17.61	1.348	1.355	0.238	0.667
25	23.58	24.13	23.68	24.24	1.349	1.355	0.164	0.333
10	34.35	35.12	34.48	35.25	1.336	1.342	0.116	0.111
0	44.77	46.03	44.77	44.77	1.315	1.315	.....	.....

The values of K_1 and D_{12} obtained from the graphs have been recorded in Table XIV together with the value of $K_{1 exp}$ and the values of D_{12} calculated on the Lenard-Jones (12 : 6) model.

TABLE XIV

Thermal conductivity and inter-diffusion coefficients from graphs

T°K	Gas Mixture	$K_1 \times 10^5$		D_{12}	
		from graph	from expt.	from graph	calculated on the $L-J$ (12:6) model
303.2	H ₂ -He	43.79		1.332	1.592
	H ₂ -Ne	43.65	43.20	1.143	1.152
	H ₂ -Kr	43.45		0.654	0.724
	H ₂ -Xe	42.87		0.621	0.618
318.2	H ₂ -He	44.99		1.620	1.729
	H ₂ -Ne	45.24	44.75	1.184	1.193
	H ₂ -Kr	45.32		0.678	0.785
	H ₂ -Xe	44.98		0.659	0.672

DISCUSSION OF RESULTS

For pure H₂, it may be seen from Table V, that all the experimental measurements of the thermal conductivity is consistently less than those given by Hirschfelder's Eq. (6) based on local chemical equilibrium assumption and so the experimental values of f_{int} are also less than the limiting value of ~ 1.3 . This discrepancy between theory and experiments as has already been suggested (Srivastava and Barua, 1960) may be due to comparatively slow rate of rotational-translational transfer of energy. It is also to be noted that Waelbroeck and Zuckerbrodt (1958) have also reached the same conclusion from their measurements on the thermal conductivity of O₂ and H₂ down to very low pressures. Actual measurements (e.g. Stewart and Stewart, 1948) show that for H₂ about 1 collision out of 300 brings about a rotational translational transfer of energy whereas practically every collision brings about a translational-translational transfer. On the other hand Eucken's derivation (i.e. $f_{int} = 1$) is based on the assumption that the rotational-translational transfer rate is negligible. The actual cases are in between the conditions imposed upon by Hirschfelder's and Eucken's derivations. Hence it is to be expected that f_{int} should lie between 1 and 1.3 which is actually found to be so.

In Tables VI–XIII it can be seen that the calculated values of K_{mix} from Hirschfelder's Eq.(9) are always higher than the experimental values. At least a part of this disagreement must be due to the higher value of the thermal conductivity of pure H₂ given by the Hirschfelder's theory. When this is corrected for by taking the experimental value of K_1 in calculating K_{mix} , it is seen that the agreement between the experimental and the calculated values of the mixture

conductivities becomes excellent. This points to the conclusion that Hirschfelder's Eq.(9) is capable of predicting correctly the concentration dependence of the mixture conductivities. A further support to this conclusion is given by the nearly straight line character of the $x-y$ graphs for the various mixtures (Figs. 3 and 4). The approximate formula of Mason and Saxena (1958) Eq. (10) is found to represent the experimental data much worse than the more rigorous formula of Hirschfelder which is apparently due to the number of approximations made in the derivation of Eq. (10).

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STATISTICAL STRUCTURE OF ANTHRONE

K. BANERJEE AND S. N. SRIVASTAVA,

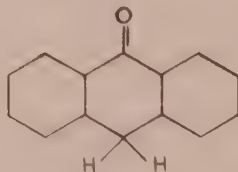
PHYSICS DEPARTMENT, ALLAHABAD UNIVERSITY, ALLAHABAD

(Received, March 22, 1960)

Plate II

ABSTRACT. The space group of anthrone was found by Srivastava to be $P2_1/a$ with 2 molecules per unit cell. This requires a molecular centre of symmetry. The chemical formula of anthrone molecule does not possess any centre of symmetry. In the rotation photographs of anthrone crystal about the symmetry axis, there occur diffuse blackenings midway between layer lines. These are also corroborated by diffuse blackenings in appropriate positions in Weissenberg photographs. A statistical structure of anthrone crystal is proposed in order to explain these apparent anomalies.

Anthrone belongs to space group $P2_1/a$ (Srivastava, 1957) with only two molecules per unit cell and having no symmetry centre in the structural formula.



Theoretically, such a situation is untenable, but very long exposure such as 130 hrs. at 30KV, 25 mA failed to show any exception to the systematic absences on which the space-group determination was based. Moreover, there appeared diffused layer lines in between the regular layer lines when the crystal was rotated about the symmetry axis b , (Fig. 1).

The position of these diffused layers were such as would have been occupied by the odd regular layer lines had the b axis been double. A Weissenberg photograph for the same rotation axis in which the first of such diffuse layer is allowed through is given in Fig. 2. In this photograph the diffuse reflections are brought clearer.

One would naturally be tempted to assume a unit cell of double this size so that the unit cell may contain four molecules, which is also the necessary number of asymmetric units needed for this space group. With the undoubled cell, the consecutive molecules along b axis should be identical as they are derived

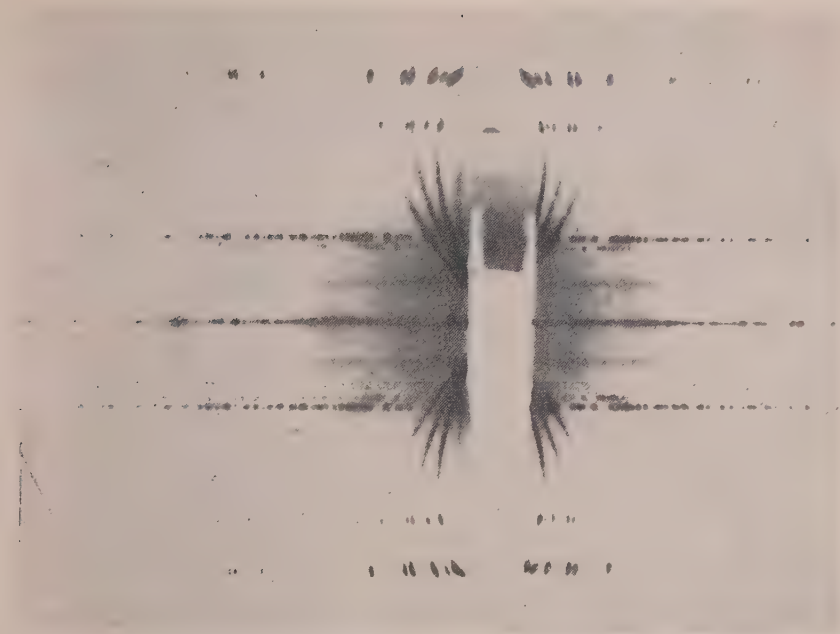


Fig. 1. Rotation about b -axis.

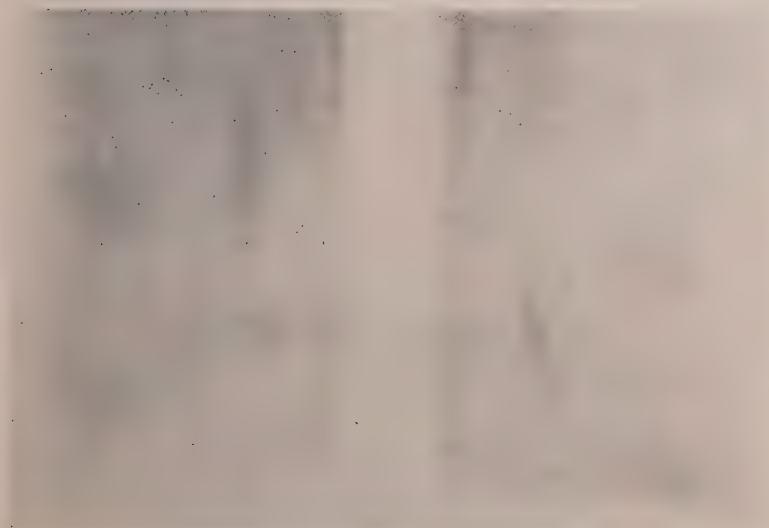


Fig. 2. Weissenberg photograph of the first diffuse layer line.

by translation, but in the doubled cell it is possible to assume the position of O interchanged with H H' in the adjacent molecule. With such a picture one can see that the contribution for hkl planes, where k is odd, can come only from the difference in the scattering powers of an oxygen atom and two hydrogen atoms attached to D and D' respectively (Fig. 1).

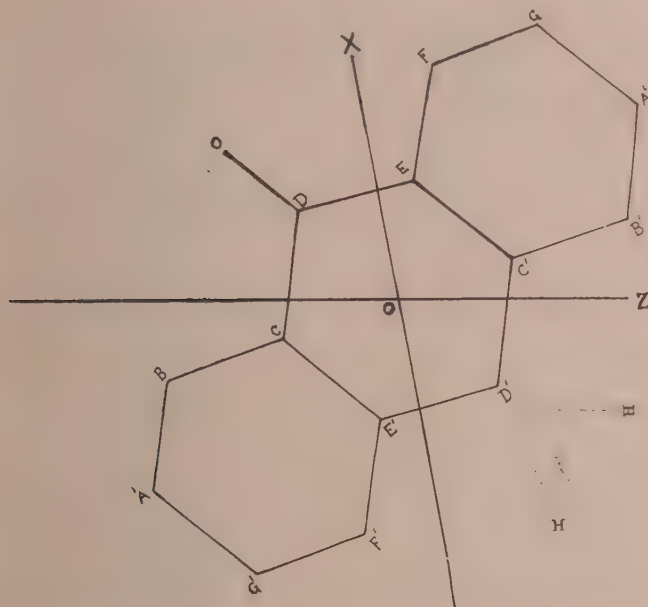


Fig. 3. (The symbol O refers to the oxygen atom and all other letters refer to carbon atoms.)

One could imagine that due to some loose bonding occurring among the O and 2H of the consecutive anthrone molecules along the b axis their bonding with the carbon atoms to which they are attached might be weakened considerably, resulting in large thermal vibrations of this group of oxygen and hydrogen atoms. This should cause irregular ties in arrangements of those atoms. This deviation from regular arrangement may be argued as reason for the appearance of diffuse layer lines for k odd values. But the diffuseness that is observed is of a much higher order than one would expect from thermal oscillations about certain mean positions. Further, diffuseness if caused in that way would also be found in spots on the regular layer lines, which is against observation. The only possible structure that can explain the facts is that of random interchange between O and 2H atoms attached to the D and D' carbon atoms. The structure is similar to that of anthraquinone with half of the oxygen atoms replaced by 2H atoms. The phenomenon is thus quite akin to that of order-disorder phenomenon in alloys. Thus each molecule of anthrone can now be considered

statistically to have half of oxygen and half of H, H' attached to the D carbon atom and the other half to D' for the purpose of calculating the structure factor for the sharp reflections. Consequently, the centre of symmetry that is necessary to be assumed to explain the X-ray diffraction spots is a statistical effect in which the oxygen and the hydrogen pair interchange positions in a random way keeping the statistical ratio the same.

The diffraction effect of such a structure can be visualised in the following way. The anthrone molecules less the oxygen and hydrogen atoms in the positions in question are arranged in the regular lattice corresponding to the space-group $P2_1/a$ and hence will give rise to diffraction maxima sharply only in the directions satisfying Laue equations corresponding to this space-group. An oxygen atom and a pair of hydrogen atoms are thus left over corresponding to each molecule. Had there been complete randomness these oxygen and hydrogen could give rise to some general scattering. The diffuse layers in between the regular layer lines show that there must be a preponderance of a periodicity double the axis length $\frac{1}{2}b$. This can happen if the oxygen atoms as well as the hydrogen pairs have a tendency to face similar atoms rather than those of the opposite kind or that the anthrone crystal consists of a 1 : 1 combination of anthraquinone and 9, 10-dihydro-anthracene and occur at random throughout the structure while maintaining the basic lattice as given above and the proportion statistically with a considerable bias for the two types occurring in alternate layers. The first alternative is, however, improbable as it would mean that the attractions between the two oxygens and also of the two hydrogen pairs of the neighbouring molecules should be stronger than those between the oxygen of one molecule with the hydrogen pair of its neighbour. The second alternative, therefore, seems to be the correct solution. The intensity distributions in the diffuse layers are being studied with a view to knowing the domains of regularities and the nature of their distributions. The structure of 9, 10-dihydro-anthracene crystal is also under investigation as it is expected that it should have an isomorphous structure with anthraquinone, if our conclusions are correct.

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OPTIMUM CONDITIONS TO OBSERVE THE NEW LIGHT EFFECT*

P. S. V. SETTY

NATIONAL RESEARCH FELLOW, DEPARTMENT OF PHYSICS, CENTRAL COLLEGE, BANGALORE

(Received, October 3, 1959; after revision, February 25, 1960)

ABSTRACT. Some experimental results with electrodeless discharge tubes containing iodine vapour are conducted with special reference to ageing. The results have shown that the effect of ageing is only the removal of occluded gases and vapours from the glass wall of the discharge tube. As a consequence of these experiments a new apparatus called the 'envelope tube' has been devised to obtain consistent results without waiting for ageing. From these results the optimum conditions for observing the new light effect have been worked out to be (a) ageing the envelope tube under low external pressure or heating it to a high temperature in vacuum till standard current voltage characteristics as shown are obtained; (b) sealing it under the above condition.

However, the cleaning up procedure recommended in this paper refers only to the external surface of the discharge tube.

1. INTRODUCTION

A glance through the vast literature on the new light effect discloses that consistent results have not been observed for the same substance by different experimenters. It might also be noted that none of the workers in that field has stated precisely the optimum conditions under which the effect can be observed. Moreover, the standard forms of the current voltage characteristics have not been worked out. In the present paper the inconsistency of results has been traced to the influence of occluded gases and water vapour in the glass wall of the discharge tube.

It has been observed that ageing of the discharge tube influences the effect considerably, sometimes increasing (Joshi and Bhat, 1942 and Deo, 1944) the percentage effect and sometimes reducing (Arnika, 1944) it. In the case of mercury vapour (Prasad and Venkateswarlu, 1949) even ageing of the discharge tubes for a long period of 424 hours could not show any light effect, whereas one discharge tube with a preliminary heating upto 200°C. for 4 hours gave an effect of 60%. This shows that ageing alone is not sufficient for observing the effect. Secondly, while investigating the new light effect, it has been observed very often, that the discharge tubes which exhibited a good light effect suddenly became inactive under certain external conditions.

* Communicated by Prof. N. R. Tawde.

The present paper concerns itself with the study of conditions under which reproducible and steady light effect can be observed. The necessary optimum conditions have been found to be (1) 'ageing' which is a cleaning up of the external surface of the discharge tube to remove the occluded water vapour as a result of passing the discharge for a long time through the tube and (2) securing a dry atmosphere surrounding the experimental tube.

2. INVESTIGATION OF OPTIMUM CONDITIONS

(a) Experiments on humidity :

A glass chamber was used in these experiments. Anhydrous calcium chloride granules were placed inside the chamber. A small paper hygrometer (Edney) was also placed inside the chamber. By adjusting the quantity of calcium chloride, the percentage humidity inside the glass chamber could be maintained at any required value. The discharge tube containing iodine vapour, at saturated vapour pressure (3 mm of mercury at 40°C), fitted with external sleeve electrodes was placed inside such a chamber. The saturated iodine vapour pressure was maintained by sealing the discharge tube with some solid iodine inside it. A 500 Watt incandescent lamp kept inside a projection lantern at a distance of 6 feet was used for irradiating the discharge tube. Precautions were taken to see that the intensity of light emitted was constant throughout the experiment. The light effect was observed with varying humidity of the air surrounding the discharge tube. The Δi values i.e. the difference between the current in dark and current under light were studied. The results are shown in Fig. 1.

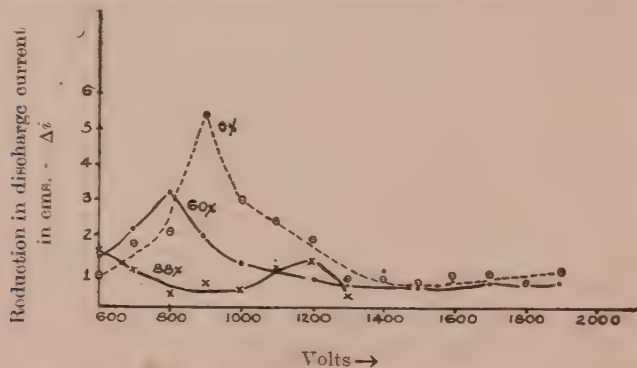


Fig. 1. Negative light effect under different humidity conditions.

The results in general have shown that the light effect and the voltage limits, in which this light effect occurs, increase as the percentage humidity of the surrounding air decreases. This shows the profound influence of humidity on the light effect.

(b) *Bell-jar experiments :*

A discharge tube containing iodine vapour at its saturated vapour pressure (3mm of Hg at 40°C) was fitted with two sleeve electrodes, of a few turns of copper wire each, kept at about 5 cm apart. This discharge tube was suspended inside a bell-jar of volume 4000 cc. by means of two copper wires connected to the sleeve electrodes. The bell-jar was kept on a bed plate with arrangements for removing air from or introducing dry air into the bell-jar.

To dry the atmospheric air a system consisting of drying agents, anhydrous calcium chloride, concentrated sulphuric acid, and phosphorus pentoxide in series was rigged up. The air, after passing through these drying agents, was introduced into the bell jar whenever necessary.

A Cenco hyvac pump was used to evacuate the bell-jar.

A paper hygrometer (Edney) which gave the relative humidity of the air directly was kept inside the bell-jar to read the humidity. A mercury manometer was attached to the system to read the pressure inside the bell jar.

3. EXPERIMENTAL PROCEDURE AND RESULTS

The experiment consisted in removing the humid air from inside the bell-jar and filling it again with dry air whenever necessary. Under these conditions readings for the light effect were taken using the conventional circuit. The results of a typical experiment are given below in Table I.

TABLE I

Date	Time	Ageing	% Humidity	Maximum % light effect	Remarks
29-10-58	1.00 P.M.	—	53	Nil	No effect
„	1.30 P.M.	30 Min.	53	Nil	„
„	1.40 P.M.	—	0 (Dry air)	18	Small & Irregular
„	2.15 P.M.	45 Min.	0	15.4	Fairly regular
30-10-58	12 Noon	—	25	16.6	Small & regular
31-10-58	12 Noon	—	30	12	„
„	1.15 P.M.	75 Min.	30	12	Not good
„	3.00 P.M.	—	20	18	Better results
1-11-58	12 Noon	—	24	16	„
„	1.30 P.M.	90 Min.	24	23	„
„	2.00 P.M.	Kept under low atm. pr. for 30 Min.	—	25	„
4-11-58	12 Noon	—	0 (Dry air)	23	„

At this stage the maximum improvement of the light effect by the reduction of humidity alone was reached. In order to remove occluded water vapour the pressure of air in the bell-jar was reduced, from 68 cm of Hg to 8 cm of Hg, in steps of 10 cm of Hg and at each step the readings for light effect were taken. As the pressure of the air decreased the light effect was found to improve gradually. After each series of experiments the bell-jar was filled with dry air. This experiment was repeated for about 3 or 4 days. By then the discharge tube had developed a large and regular light effect. The experimental results after this date are given in Table II.

TABLE II

Date	Time	% Humidity	Maximum % light effect	Remarks
7-11-58	12 Noon	0 (Dry air)	52	Large & regular
12-11-58	"	30	61	A bit irregular
14-11-58	"	0 (Dry air)	65	Large & regular
17-11-58	2.00 P.M.	23.5	50	Reduced
"	3.00 P.M.	0 (Dry air)	68	Better results
18-11-58	12 Noon	0	69	"
19-11-58	"	0	65	"
21-11-58	"	26	69	Consistent repro- ducible results (shown in Fig. 3).

The current voltage characteristic and the Δi voltage characteristic as obtained till November 19, 1958 are shown by a set of typical curves in Fig. 2.

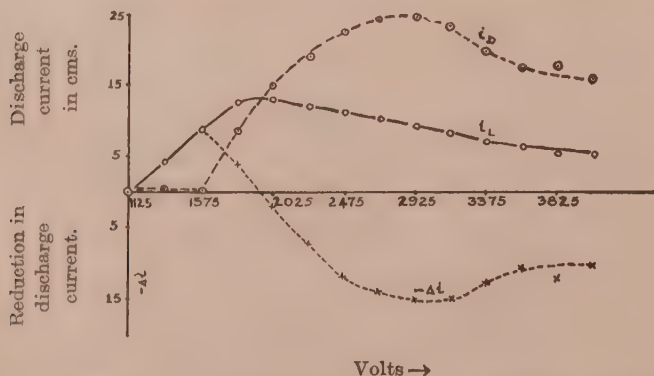


Fig. 2. Characteristic curves not under optimum conditions.

The readings for light effect taken after reaching the steady state showed a definite change in current voltage characteristics giving the standard forms of these curves. They are shown in Fig. 3 from which it is obvious that an ageing process extended over about a fortnight enabled consistent results to be obtained with the tube inside the bell-jar. It is interesting to note that when the discharge tube was removed from the bell-jar the same characteristics could not be obtained.

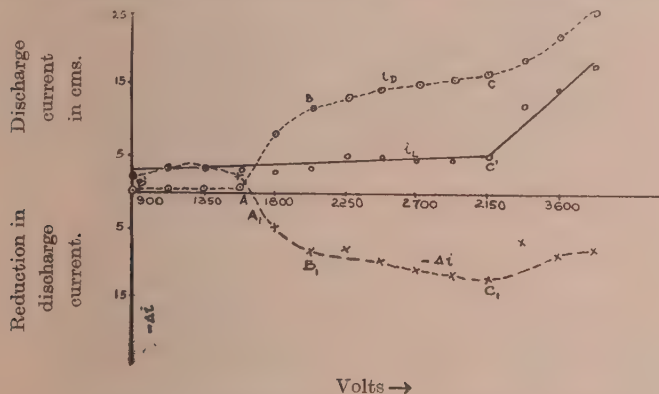


Fig. 3. Characteristic curves under optimum conditions.

The above account shows that consistent results can be obtained by the removal of occluded water vapour from the walls of the discharge tube after a tedious process extending over a large period. To obviate this difficulty a new apparatus was devised which may be called 'envelope tube' whose description and working is given below.

4. ENVELOPE TUBE EXPERIMENT

A short note giving a preliminary description of the envelope tube and its working was published recently (Setty, 1959). The discharge tube (Fig. 4) is a co-axial double tube in which the space between the inner and the outer could be evacuated while the inner tube serves as the discharge tube. The sleeve

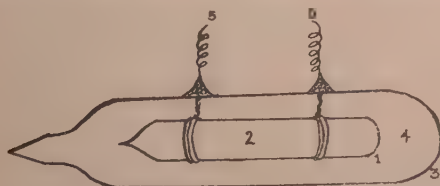


Fig. 4. Envelope Tube.

- (1) Discharge tube. (2) Iodine vapour. (3) Envelope. (4) Perfectly dry air in between discharge tube and envelope. (5) Electrodes.

electrodes wound round the discharge tube were brought out by sealing them through the glass envelope. The whole apparatus was heated to a temperature

of 400°C and the envelope was evacuated using an oil diffusion pump for sufficient period and then refilled with dry air to the required pressure and sealed off. In some tubes the space was left as a vacuum. After the discharge tube cooled to the room temperature it was tried for the light effect. Results obtained with both types of tubes agree. A typical result obtained under these conditions is given in Fig. 5 which resembles Fig. 3 pertaining to bell-jar experiments in every respect.

5. EXPERIMENTAL RESULTS

A comparison of Figs. 3 and 5 shows that both of them are almost identical. But a distinct difference is observed between these and results in Fig. 2.

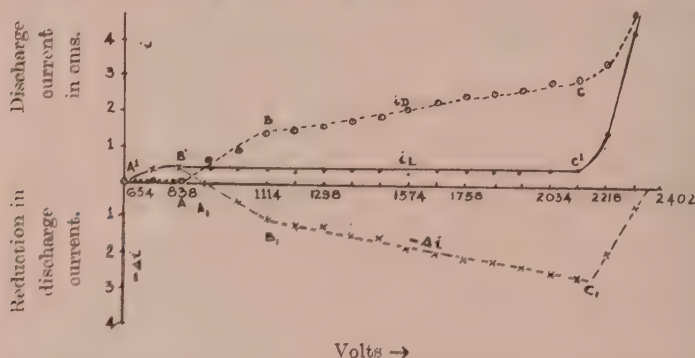


Fig. 5. Characteristic curves under optimum conditions with envelope tube.

In Fig. 2 all the characteristics (i_D , i_L and $-\Delta i$) start at some particular voltage and reach a maximum at a higher voltage beyond which they diminish considerably.

In Figs. 3 and 5 the characteristic i_D starts at a particular voltage A , increases rapidly upto a higher voltage B , beyond which the increase is gradual throughout the voltage up to C . After this point C the characteristic i_D suddenly shoots up. The characteristic i_L starts at a particular voltage A' , increases rapidly upto a higher voltage B' beyond which it is almost parallel to X axis till the point C' . After the point C' this also shoots up and meets i_D characteristic. Thus i_D and i_L do not show any tendency of diminishing at any voltage.

$-\Delta i$ characteristic starts at a particular voltage A_1 , increases rapidly upto the point B_1 beyond which the increase is gradual upto C_1 . But after C_1 it suddenly diminishes and meets the X axis showing the absence of light effect.

6. DISCUSSION

The first set of experiments with the tube inside the glass chamber reveals that the humidity of the atmosphere surrounding the tube brings down the light

effect in accordance with Fig. 1. It is clear from Fig. 1 that the maximum value of the negative light effect ($-\Delta i$) goes on decreasing with the increase of the percentage humidity of the surrounding atmosphere. The second peak for 88% humidity at 1200 volts is a non-repeatable one, showing that the conditions for observing the light effect are not optimum. The second set of experiments points out the influence of gases and vapours occluded in the walls of the discharge tube, the results on the releasing of which is indicated in Figs. 2 and 3. The curves in Fig. 2 establish beyond doubt that as the occluded gases and vapours are removed from the walls of the discharge tube, the light effect observed not only goes on increasing but the voltage limits in which it occurs also increase enormously. That the process of ageing heats the discharge tube is supported by Mackinnon (1928) and Viswanathan (1951). That the occluded gases and

TABLE III

Percentage light effect observed with the Envelope Tube at different intervals

Volts	% light effect			
	11-2-59 (I)	11-2-59 (II)	19-2-59	25-2-59
1001	54.5	44.4	—	38.0
1092	69.7	63.0	50.0	60.0
1183	70.0	69.7	59.3	68.0
1274	73.5	74.4	63.0	71.4
1365	74.5	70.8	65.5	73.8
1456	75.5	74.5	67.0	75.2
1547	76.0	78.4	70.5	74.4
1638	78.4	78.0	71.6	74.0
1729	76.8	75.4	75.0	74.0
1820	75.4	72.9	75.7	71.4
1911	75.0	73.0	76.0	69.4
2002	74.0	71.7	79.4	72.0
2093	74.3	73.6	80.5	71.7
2184	67.0	69.0	77.4	70.0
2275	45.8	39.0	67.4	67.6
2366	0	0	53.2	53.1
2457	0	0	0	0

vapours are liberated when heated in vacuum is supported by Jnanananda (1947). Hence it might be gathered that the removal of water vapour and occluded gases is a pre-requisite for obtaining consistent results in light effect experiments. Reproducibility of results becomes difficult because one has to wait for ageing each time the experiment is started.

The new apparatus devised remove the above difficulty of ageing once and for all. The envelope tube can be used at any time and consistent results are obtained without any preliminary drying or ageing. The consistency of the results are considered here only from the point of view of the form of the curves and not from the voltage characteristics as the thickness of the wall of the discharge tube may interfere with the voltage. The readings of the percentage light effect observed with the envelope tube at different intervals but under the same experimental conditions shown in Table III clearly indicate that the results are consistent.

It is suggested that much of the previous work (Joshi and Bhat, 1942; Arnikar, 1949; Deo, 1944; Prasad and Venkateswarlu, 1949; Joshi and Kuppuswamy, 1941; Joshi and Deshmukh, 1942; Joshi and Murty, 1942, and Gopalaswamy and Viswanathan, 1949) yielding somewhat contradictory results be repeated with this new apparatus so that a theoretical explanation of the light effect becomes possible.

Thus the optimum conditions for the observation of the low light effect in A/C silent discharges are the following :

1. The envelope tube should either be aged under low external pressure or heated in a vacuum till it gives most likely the standard characteristics as shown in Fig. 5.
2. Under the above condition the envelop is sealed with a perfectly dry air at the required pressure or sealed with a perfect vacuum.

7. ACKNOWLEDGMENT

Author's grateful thanks are due to Prof. S. B. Bondade for his kind help, encouragement and interest in the work. The author also wishes to take this opportunity of expressing his gratitude to Sri H. K. Vittal Rao for preparing the necessary discharge tubes, to Sri H.S. Venkataramiah for his valuable suggestions and to the Ministry of Scientific Research and Cultural Affairs for awarding a National Research Fellowship to him.

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Letters to the Editor

The Board of Editors will not hold itself responsible for opinions expressed in the letters published in this section. The notes containing reports of new work communicated for this section should not contain many figures and should not exceed 500 words in length. The contributions must reach the Assistant Editor not later than the 15th of the second month preceding that of the issue in which the paper is to appear. No proof will be sent to the authors.

5

ABSORPTION SPECTRA OF *O*-, *M*-and *P*-HYDROXY-BENZALDEHYDES

I. ACHYUTA RAO AND V. RAMAKRISHNA RAO

DEPARTMENT OF PHYSICS, ANDHRA UNIVERSITY, WALTAIR

(Received, January 29, 1960)

The near ultraviolet absorption spectra of ortho, meta and para hydroxy benzaldehydes have been studied in the vapour phase. Earlier workers (Morton and Stubbs, 1940) studied mainly the absorption spectra of their solutions in various solvents and reported band data for the vapour spectra also, but no vibrational analysis was made.

In the present work, two systems of bands have been observed in each of the ortho and meta isomers (only one system of bands was reported earlier (Morton and Stubbs, 1940) and one system in the para isomer, in the regions indicated below :

Ortho :—3630—3270A (System I)
2670—2330 A (System II)

Meta :— 3125—2890A (System I)
2500—2395A (System II)

Para :— 2915—2660A

The band data also have been extended and a systematic vibrational analysis has been made.

Ortho : In System I about fifty bands are measured. The 0, 0 band is chosen at 3537.6A (28260 cm^{-1}). The bands are interpreted on the basis of three (269, 426 and 558 cm^{-1}) ground state fundamentals and seven (263, 410, 523, 671, 937, 1013 and 1201 cm^{-1}) upper state fundamentals.

In System II about One hundred and thirty bands are measured (only thirty-three were reported earlier) . The 0, 0 band is chosen at 2524.6A (39598 cm^{-1}).

The bands are interpreted on the basis of seven (263, 437, 562, 776, 1032, 1232 and 1689 cm^{-1}) ground state fundamentals and eight (245, 440, 518, 763, 943, 1161, 1198 and 1503 cm^{-1}) upper state fundamentals.

Meta : In System I about twenty-five bands are measured. The 0,0 band is chosen at 3092A (32332 cm^{-1}). The bands are interpreted on the basis of one (249 cm^{-1}) ground state fundamental and three (189, 392 and 947 cm^{-1}) upper state fundamentals.

In System II about thirty bands are measured (only nine were reported earlier). The 0,0 band is chosen at 2478\AA (40343 cm^{-1}). The bands are interpreted on the basis of one (243 cm^{-1}) ground state fundamental and six (213, 428, 494, 628, 814 and 967 cm^{-1}) upper state fundamentals.

Para : In this case only one system was found. About thirty bands are measured (only eleven were reported earlier). The 0,0 band is chosen at 2836A (35251 cm^{-1}). The bands are interpreted on the basis of three (394, 635 and 861 cm^{-1}) ground state fundamentals and eight (174, 326, 529, 787, 996, 1142, 1181 and 1267 cm^{-1}) upper state fundamentals.

The upper state and lower state fundamentals observed in the three isomers have been correlated with the Raman data reported by Kohlrausch (1938).

Details will be published shortly.

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INDUCED LIGHTNING STROKES

S. D. CHATTERJEE AND B. K. DUTTA

DEPARTMENT OF PHYSICS, JADAVPUR UNIVERSITY, CALCUTTA-32

(Received, March 11, 1960)

The mechanism of direct cloud-to-ground lightning strokes have been extensively studied by Schonland (1950), McEachron (1939) and others from photographs taken with modified Boys camera. The surges of direct lightning strokes to the power and telephone lines, and induced effects due to charge induced on the line by an overhead thundercloud have also been subjected to careful analysis by Peek (1924). And yet direct photographic evidences of induced lightning strokes are rare.

During the monsoon season at Calcutta, two interesting still shots of induced lightning strokes were taken from the same spot on two consecutive evenings. It appears that the local terrain produces great localised variations in storm and lightning-stroke density.



Fig. 1: Two cloud-to-ground direct lightning strokes accompanied by a fencing post-to-ground induced lightning stroke. Sprouting positive streamers on the ground.



Fig. 2: Induced double lightning stroke from two incandescent lamps mounted on lamp posts to the ground. Faintly luminous tracks of an earlier double flash over in the background. Zig-zag "St. Elmo's fire" from a receiving aerial on the roof of a double storeyed building on the right.

Fig. 1 depicts two cloud-to-ground direct strokes accompanied by an induced stroke which links a barbed-wire-fencing post with the ground. The high luminosity of the latter suggests that it is probably a return stroke which follows the junction of a stepped leader with a positive streamer coming from the ground. Some faint points of luminiscence on the ground in the neighbourhood of the flash may be other sprouting positive streamers which failed to connect with the leader.

Fig. 2 shows a tantalizing photograph, which was taken on the second evening amidst a crescendo of lightning flashes and peels of thunder, occurring within a couple of hundred feet of the camera. It seems that a violent, swiftly oncoming storm, unaccompanied by rain, induced a heavy charge density upon the ground surface. As the magnitude of the ground gradient rapidly increased, the accumulated electric stress between the ground and two street lamps caused almost simultaneously a double flash-over. The electric lamps were mounted on two eighteen feet high steel posts carrying overhead supply lines and were situated at a distance of ninety feet from each other. An earlier double flash-over between the ground and two other incandescent electric lamps protruding from the walls of a building is revealed by a faintly luminous double streak in the background. Presumably the earlier flash-over had taken place within 0.5 second before the opening of the camera shutter. Malan and Collens (1938) have reported data on luminiscence of heavy discharges whose duration ranges in extreme cases from a few hundred microseconds to half a second. Although the electrostatic lines of force from the origin of the stroke to the ground should form essentially smooth curves, the picture shows tortuous paths interspersed with loops. These may be attributed to some variable condition at the head of the discharge, this condition being either variations in the head itself or variations in space ionization. However, the strict parallelism of the two sets of double strokes indicate preponderance of the latter factor. It is indeed amazing that even the corona or "St. Elmo's fire" emanating from a receiving aerial on the roof of a right-hand-side building exhibits an analogous zig zag pattern.

Assuming 5000 volts per cm as a fairly acceptable value (Creighton, 1937) for the average gradient at the surface of the earth for spark-over between two sharp points, the maximum induced potential on each of the street lamps should be about two million volts, while that on the verandah lamps about half of this value. Nevertheless, the length of the individual luminous paths indicates that the induced voltage is of the order of 12 million volts.

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THE NEAR ULTRAVIOLET ABSORPTION SPECTRA OF *M*-and *P*-METHYL ANISOLES

K. V. KAMESWARA RAO AND V. RAMAKRISHNA RAO

DEPARTMENT OF PHYSICS, ANDHRA UNIVERSITY

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The near ultraviolet absorption spectra of meta- and para methyl anisoles were investigated in the vapour, liquid and solid phases.

m-Methyl anisole. In vapour absorption about 45 bands were measured and the intense band at 2773.3\AA (36048 cm^{-1}) was taken as the (0, 0) band. The spectrum could be interpreted on the basis of seven fundamental frequencies in the upper state (210, 676, 824, 952, 1092, 1164 and 1228 cm^{-1}) and two fundamentals in the ground state (206, and 725 cm^{-1}). There is agreement with Raman data reported by Reitz and Ypsilanti (1935).

In liquid absorption four bands were obtained and the intense band at 2807\AA (35615 cm^{-1}) was taken as the (0, 0) band. The spectrum could be interpreted on the basis of one upper state fundamental 911 cm^{-1} .

In solid absorption three bands were obtained and the intense band at 2805\AA (35640 cm^{-1}) was taken as the (0, 0) band. The spectrum could be interpreted on the basis of one upper state fundamental 926 cm^{-1} .

p-Methyl anisole. In vapour absorption about 32 bands were measured and the intense band at 2824.1\AA (35399 cm^{-1}) was taken as the (0, 0) band. The spectrum could be interpreted on the basis of six fundamentals in the upper state (379, 480, 544, 789, 1176 and 1259 cm^{-1}) and two fundamentals in the ground state (530 and 839 cm^{-1}). There is agreement with Raman data reported by Reitz and Ypsilanti (1935).

In liquid absorption two bands were obtained and the intense band at 2869\AA (34845 cm^{-1}) was taken as the (0, 0) band. The other band was interpreted as the upper state fundamental 795 cm^{-1} .

In solid absorption about ten bands were obtained and the intense band at 2872\AA (34809 cm^{-1}) was taken as the (0, 0) band. The spectrum could be interpreted on the basis of two upper state fundamentals (780 and 1229 cm^{-1}).

The details will be published shortly.

REFERENCE

Reitz, A. W. and Ypsilanti, G. P., 1935, *Monats. Fur. Chem.* **66**, 304.

200. S. K. KAMESWARA RAO AND V. RAMAKRISHNA RAO

BOOK REVIEWS

ADVANCES IN CHEMICAL PHYSICS, VOLUME II. Edited by I. Prigogine.
Pp. 412+viii. Interscience Publishers, New York; London, 1959. Price
\$11.50.

This volume consists of nine articles on different topics contributed by different authors. The first article entitled Clathrate solutions contributed by J.H. Van der Waals and J. C. Platteeuw starts with the discovery and designation of these compounds and then gives a statistical theory of formation of the compounds. The third section deals with hydroquinone clathrates in binary and tertiary systems. The article includes a list of 58 references.

The second article by K. S. Pitzer is on inter- and intra-molecular forces and molecular polarizability. Wave mechanical theory for many-electron systems has been discussed first and the results predicted by the theories have been next compared with experimental results. Finally, intramolecular applications and anisotropic effects have been dealt with in detail. The list of references includes 42 papers.

The third article by J. S. Rowlinson and M. J. Richardson deals with solubility of solids in compressed gases. Recent work on 17 simple systems has been discussed in detail and a brief outline of the theory has been given. A list of 90 references has been included at the end of the article.

In the fourth article entitled 'Thermodynamics of metallic solutions' R. A. Oriani has reviewed the work done in this line since the discovery of superlattices in 1919. A list of 71 references has been given in this article.

The fifth article by M. Szwarc deals with recent advances in polymer chemistry. The topics discussed are Addition polymerization, Initiation of polymerization, Propagation of polymerization and Termination. A list of 57 references has been included.

The sixth article entitled Nuclear Quadrupole Resonance in Irradiated Crystals contributed by Jules Duchesne deals mainly with the effect of high energy radiation on solids as studied by quadrupole resonance. A list of 34 references is included in this review.

The seventh review by Per-olv Löwdin deals with correlation problem in Many-Electron Quantum Mechanics. This is a lengthy review covering a wide field of theoretical work in this line. Starting with Schrodinger Equation for an electronic system, the article deals with the effect of two-particle repulsion and

then gives in detail the Hartree-Fock scheme. The theory is then applied to specific cases, such as, He, alkali metals, etc. Extended Hartree-Fock scheme for constructing pure spin functions has also been discussed. The article includes a list of 42 references.

The eighth article is also of the same title in which Hiroyuki Yoshizumi has made a bibliographical survey of the historical development of the subject.

In the last article by Bright Wilson Jr. "the Problem of Barriers to Internal Rotation in Molecules" has been discussed and different methods for the measurement of the potential barriers have been described. A list of 35 references has been given in this review.

It can be seen from the above paragraphs that the book is extremely useful to physicists as well as chemists interested in the modern theories about the different phenomena covered in the articles.

S. C. S.

ADVANCES IN SPECTROSCOPY, VOLUME I. Edited by H. W. Thompson. Pp. 363 + viii. 15cm x 23cm. Interscience Publishers Inc., New York, 1959. Price \$ 12.50.

This volume contains eight articles reviewing work done in eight different selected lines of research in spectroscopy. The review entitled "The spectra of polyatomic free radicals" by D. A. Ramsay deals with the different methods of producing free polyatomic radicals. The spectrograms of a few such radicals have been reproduced in this article. The results of analysis of a large number of triatomic and a few polyatomic free radicals have been discussed in details. An exhaustive list of references has been given at the end of the review.

In the review of work on "Spectroscopy in the vacuum ultraviolet" written by W. C. Price the author has dealt with the experimental arrangement for studying the spectra in this region of atoms and molecules and a list of references has been given. No discussion of experimental results has been included in this review.

D. H. Rank has briefly discussed in two separate articles the Index of refraction of air and Determination of velocity of light.

The fifth article on "High resolution Raman spectroscopy" by B. P. Stoicheff deals mainly with the Raman spectra of polyatomic molecules in the gaseous state at high resolution. Many beautiful rotational Raman spectra of vapours obtained by the author himself using a new technique developed by him have

been reproduced. The results obtained for symmetric and asymmetric top molecules have been discussed in detail.

Under the title "Modern infrared detectors" T. S. Moss has discussed the properties of thermal detectors, photo conduction infrared detectors and indium antimonide detectors.

The infrared spectra of polymers have been discussed by A. Elliott who has given a complete bibliography of the papers published on this subject at the end of the review.

Finally, N. Sheppard has discussed the rotational isomerism about C—C bonds in saturated molecules as studied with the help of infrared and Raman spectra. He has also given an exhaustive list of references.

The book is very useful to research workers interested in the branches of spectroscopy mentioned above. The get-up is excellent.

S.C.S.

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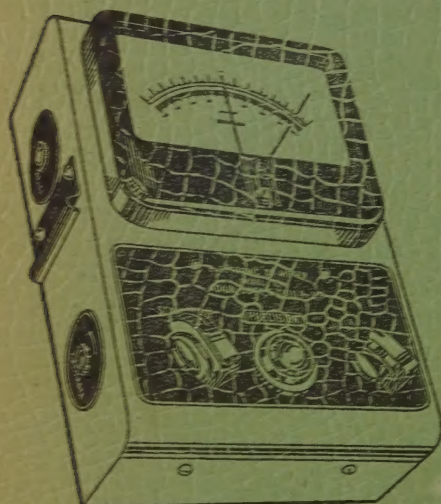
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